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ANALYSIS OF TRENCH DRAIN SYSTEMS
BENEATH FOUNDATIONS

A Special Research Problem

Presented to

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by

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ABSTRACT

This study is an analysis of the performance characteristics of a trench drain system used for foundation dewatering. By the uses of a finite element analysis program the trench drain system performance will be modeled.

Through the use of dimensional analysis techniques the results of the system modeling will be used to prepare a means of predicting the system performance for a wide range of variables.

As an economic concern the trench drain system will be compared with the common blanket drain. This comparison will provide information necessary for the selection of the method most economical for the application.

The trench drain characteristics of primary concern are the total system flow and the maximum free surface height of the water between trenches. The determination of the radius of drawdown for the system is a vital element of the prediction process and is a major portion of the study.

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CHAPTER 1

TRENCH DRAIN SYSTEM

I. Introduction:

Shallow foundations are susceptible to damage and leakage from the hydraulic forces of groundwater. The pressure of water will damage walls, pass into the structure through cracks and holes and contribute to the deterioration of metal, wood and concrete structural members. A structure will not satisfactorily full fill the intention of the owner if water gathers in the basement or garage of the building. A great deal of effort is expended by builders, owners and designers attempting to prevent water from infiltrating a foundation or collecting behind the walls. The most simple solution, as well as the most effective and economical is to properly design the foundation so that water is not present to penetrate the structure.

For a shallow foundation positioned at a moderate depth below a water table the foundation trench drain system is an alternative to expensive water resistant methods of construction. The foundation trench drain system is an application of a very old technique. A trench filled with highly permeable granular material collects water from surrounding, less permeable soil and carries it by gravity flow and slope to a sump or outfall,

where the water can be removed or wasted. Today the flow is usually in slotted pipes within the granular trench. Since the water can be removed from the highly permeable soil more quickly than it can exit the less permeable soil a difference in elevation of the water levels of the two soils is created. This gradient serves to provide continued flow as long as the gradient exists.

The gravity flow method is obviously very easy to implement and generally inexpensive. It does not always work well to dewater or drain a site sufficient to accomplish construction. It is usually not effective to attempt dewatering by gravity flow when (Powers, pg.236):

- a. Soil is a loose granular deposit without plastic fines.
- b. The soil has a high permeability.
- c. There is a proximate source of large recharge to the water table such as a lake or river.
- d. The aquifer is artesian or bounded under a positive head by an impermeable upper surface.
- e. The depth to be dewatered is large so that there will be a high gradient between the water table and the base of the foundation.

If the soil to be dewatered does not have the limiting conditions gravity dewatering still might not be

advisable. The tendency of a soil to hold water is called storage. All soils will retain water by capillary tension while the apparent water table level is drawn down. A soil with a high storage have a surprisingly large amount of water held above the water free surface(Powers, pg.114). Removal of the held water may require energy in the form of pumping.

For this study the trench drain system for dewatering beneath a foundation will be evaluated. The evaluation will be done assuming that construction of the foundation is complete and construction dewatering has lowered the free water surface to below the design final elevation. The trench drain system will maintain the free water surface at the final elevation and not in contact with the foundation.

II. Purpose of the Study:

In this study the characteristics of a trench drain system will be evaluated with the use of the Aral Seepage Program, a finite element analysis program. Under a range of normal variables a trench drain system will be evaluated to determine; (a)the output flow of the system under the different configurations, (b)the range to which drawdown of the water table can be expected and (c)the maximum rise of the free water surface between the trenches.

The results of the finite element analysis will be grouped under dimensional analysis to provide a model for prediction of the characteristics. The predictive method will be effective within the range of variables considered.

Finally a cost analysis of the trench drain system as compared to a blanket drain system. With this information a designer will be able to effectively select the most cost efficient solution to the problem considered if the choice is between the trench drain and the blanket drain system.

CHAPTER 2

PREPARATIONS FOR THE ANALYSIS

I. Introduction:

In preparation for collecting data to analyze the dewatering capacity of a trench drain system planning was necessary to facilitate the assimilation of results. Dimensional analysis, used in presenting the results of this study is briefly reviewed in this chapter.

As with all numeric seepage calculations the area to be dewatered is of critical importance. The size of the cone of depression or the radius of influence is the single most difficult parameter to establish. Many rules of thumb, observations and formulas exist from which the radius of influence is determined in practice. To predict the rate of flow and water table drawdown the radius of influence must be determined. The evaluation of the radius of influence for use with the Aral Seepage Program is reviewed in this chapter.

The Aral Seepage Program, a finite element analysis, used in evaluating the trench drain system of this study was detailed by an earlier study (Pirtle, Appendix A). In preparing for runs of this program several items were noted which amplify the instructions of the user's manual.

11. Dimensional Analysis:

In this study the modeling of a large trench drain system used, for dewatering beneath a foundation, was done using a finite element analysis program. There are an infinite number of geometries and conditions for such a system and it is not practical to run the program for each combination of dimensions and properties. The goal, to provide a detailed summary of the expected results for any single group of conditions from the results of a few models, requires a range of variables covering normal values. Results cannot be specific to a few configurations of the system.

Dimensional analysis is a systematic grouping of variables into a dimensionless product. The product can represent a very small model of the system or a full size application. The trends and results predicted from a collation of the dimensionless numbers will be true for any combination of variables. From a dimensionless number the quantity of flow or free surface elevation between trenches can be evaluated for an infinite number of conditions.

In arriving at the dimensionless numbers for use in evaluation, the variables must be identified and cataloged by dimensions (Langhaar, Chap 3). The variables are then grouped into dimensionless products. The results of this

study of trench drain systems is presented in terms of dimensionless products. From inspection and experimentation the dimensionless numbers which provide the most insight are used in evaluating the models.

The variables in the study of dewatering a foundation by use of trench drains are listed:

- radius of influence (L), units of length
- hydraulic conductivity, horizontal (k_h), units of length/time
- hydraulic conductivity, vertical (k_v), units of length/time
- trench spacing, (S), units of length
- trench width, (d), units of length
- free head above trench bottom, (h), units of length
- aquifer thickness, ($h+H$), units of length
- number of trench drains, (N), no units
- slope of aquifer, (p), no unit

For this study only four trench drains were considered so no range of variables will be available from which to reasonably predict the characteristics of systems with other than four drains. The affect of other than four drains will not be considered. With a dimensionless product, later studies may determine a correlation between a four trench system and other configurations.

The aquifer slope will often be zero or near zero. A multiple of zero will reduce any dimensionless number to zero so the slope will also not be used in the dimensional analysis. Slope is a critical variable and the influence of aquifer slope will be shown by individual results and trends. For intermediate results interpolation between of the considered slopes will be necessary.

The width of drainage trenches considered for this study was restricted to one value. The trench width varies in practice and a value of 1.5 feet provides the minimum space necessary for placement of drainage pipe and granular backfill. If it is more necessary to make the trenches wider, the amount of dewatering will increase (Pirtle, Chap 4) and there will be less hydraulic rise in the water table between trenches. A wider trench is a more conservative approach and the variable for width of trench drains is included as a dimensional consideration.

Hydraulic conductivities, vertical and horizontal, are the only variables with other than a length dimension. This complicated the forming of dimensionless products. The vertical and horizontal conductivities had to be in the product, which left five variables, all with a single length dimension. There are five combinations to form a dimensionless product, each with six alternative

arrangements. This study was done with the vertical conductivity (k_v) equal to the horizontal conductivity (k_h) so the combinations for experimentation are:

$$\begin{array}{llll} L, d, S, h & L, d, S, (H+h) & L, d, h, (H+h) & (1) \\ & L, S, h, (H+h) & S, d, h, (H+h) & \end{array}$$

Each grouping has six different arrangements, yielding thirty possible dimensionless products. The results of the model runs were prepared in the dimensionless form. The products were compared and the arrangement which provided an insight into a relationship to total flow and the maximum free surface was selected for use. In this case the final product is:

$$Ld/h(h+H) \quad (2)$$

The variable not included in the product was the trench spacing. In Chapter 4 trench spacing is considered in evaluating the total flow and the maximum free surface between trenches.

III. Radius of Influence:

The distance over which the water level is lowered by dewatering is commonly referred to as the radius of influence. The radius of influence is the distance from the point or line of water removal to a point where the water table is not affected by the dewatering operation.

Obviously any model of dewatering or pumping operations is dependent on the radius of influence.

The radius of influence can be accurately determined in the field by a pumping test. A pumping test, using a fully penetrating well in an unbounded aquifer not in contact with a body of water, will provide a measured output and drawdown at known radii. The drawdown when plotted against the log of time will allow for the calculation of the effective conductivity of the soil. Under the Dupuit assumptions mathematical models ((a) Powers, pg 100) can project a drawdown for various distances and pump outputs. Calculation of the radius of influence is also available with this method. For a trench drain system the pumping test method has several problems. The trench drain is a method of open pumping or gravity flow and will have a significantly lower output than would a pumped well. By its nature the trench drain system is longitudinally aligned and would not be modeled by a well with accuracy. The trench drain does not fully penetrate the aquifer and will offer a different output than a fully penetrating well (Leonards, pg 270).

It is not unusual for the radius of influence to vary greatly, often differing by an order of three to four magnitudes ((a) Powers, pg 108). The radius of influence is affected by every variable of the system. In general the radius will increase with time and as the drawdown is

increasing. For pervious soils the radius of influence is greater than for a soil of less hydraulic conductivity (Leonards, pg 261). In the evaluation of a trench drain system, after construction of the foundation, the dewatering has reached a steady state condition. The effects of time and initial drawdown will not be considered in this study.

Normally the radius of influence is selected based on knowledge of the area and experience with design of dewatering systems. Several formulas exist to calculate the radius of influence, usually considering the hydraulic conductivity, thickness of aquifer, free head above point of lowest drawdown and adjustment factors. Several formulas are listed below:

Means of Calculating the Radius of Influence

1. $Q = (.73 + .27(H - h_o)/H) (kx/2L) (H^2 - h^2)$

Gravity flow to a partially penetrating slot (Leonards, pg. 271) with Q =total flow, H =aquifer thickness, h_o =elevation of water in trench, x =length of trench, k = permeability and L =radius of influence. Use consistent units.

2. $L = 3.8h$

Highway subdrainage design (Moulton, pg 60) with h =drawdown in water level in feet, L =radius of influence in feet.

$$3. R_o = 3hk^{1/2}$$

Radius of influence as a function of drawdown ((a)Powers, pg. 109 after Sichart) with R_o =radius of influence, h =drawdown. Use consistent units.

$$4. Q/x = K(H^2 - h^2)/L$$

Water table flow from a line source to a drainage trench ((a)Powers, pg. 100). Q/x is the total flow per unit length of trench, k is permeability, H = thickness of aquifer, h = trench elevation, L = radius of influence. Use consistent units.

$$5. G = S_y Lq / KH^2$$

Predictive Analysis of Groundwater Inflows into Excavations (Freeze, pg. 494). G =a dimensionless discharge, S_y = specific yield, normally .01 to .3 (Freeze, pg. 61), K = hydraulic conductivity, H = aquifer thickness, q = rate of flow per unit length of trench, L = radius of influence. Use consistent units.

These formulas and others will predict a radius of influence for the characteristics of the problem. The prediction of a radius of influence for the foundation trench drain system is discussed in Chapter 4.

The radius of influence is an input value in the Aral Seepage Program. The program will calculate a quantity of flow and a water level free surface for a given radius of influence. The formulas from above and several others offer severe limitations to predicting the radius of influence. The formulas are not specifically for a trench drain system and to various degrees do not account for variations in horizontal and vertical permeability, partial penetration of the aquifer and gravity flow.

Water is produced from an unconfined aquifer by three mechanisms: (1) expansion of the water under reduced fluid pressures, (2) compaction of the aquifer under increased effective stress and (3) dewatering of the unconfined aquifer (Freeze, pg 324). In a gravity flow trench system water is not removed from the aquifer but, is carried away after it enters the trench (or leaves the aquifer). The water will leave the aquifer at a rate consistent with the Darcy principal, $Q = kiA$. Once steady state is attained the area, A becomes constant and so too is the flow. The amount of drawdown over the distance from trench to original water level (radius of influence) is the hydraulic gradient, i . The permeability is a property of the soil and is assumed to remain constant. The gradient in a steady state gravity flow system can only change with a rising (infiltration)

or lowering (depleted) water table. To change the gradient in a stationary water table an outside action must take place to change the fluid pressures or to physically remove water from the aquifer. Pumping would be a means of changing the gradient and hence the radius of influence and outflow of the system.

The theoretically correct radius of influence for ideal conditions was determined by running each trench drain configuration at a series of different radii. The resultant total flow of the system were plotted against the trial radii of influence. Total flow is the cumulative outflow from all four trenches. Figures 2-1 through 2-12 are the results of the runs. The above discussion shows the radius of influence to be at the distance where no further drawdown occurs. The trial radii greater than the true radius of influence yields a result at the true free surface. Lesser trial radii results in a forced solution with a larger gradient and higher flow. For this study the radius of influence was selected from the figures 2-1 through 2-12 as the distance where flow became constant.

Establishing the distance where total flow remained relatively constant required a uniform criterion to define unchanging flow. Arbitrarily, unchanging total flow was defined as 10% change over a 100 foot change in radius. This definition was selected after comparison of

the results across the thirty six different configurations of the problem as studied. For this problem, assuming a trench length of 200 feet the 10% change criterion is less than .05 gpm total flow.

The radius of influence is an extremely variable value, subject to interpretation and fine measurement. An accuracy of fifty feet was established as a reasonable estimation for the correct radius of influence.

Radius of Influence

(slope = 0%, $H = 20'$, $h = 10'$)

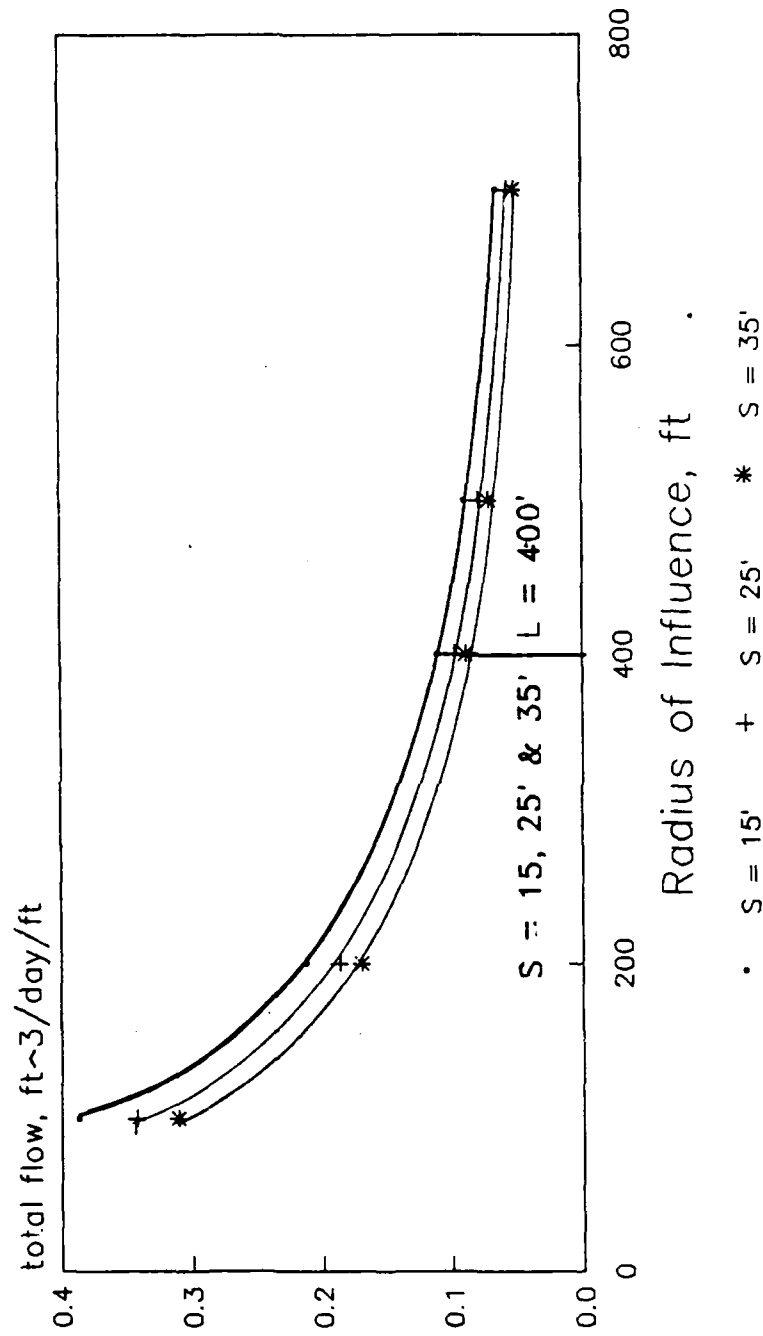


Fig. 2-1
Determination of radius of influence
 S = Spacing, L = Radius of Influence

Radius of Influence

(slope = 0%, $H = 20'$, $h = 20'$)

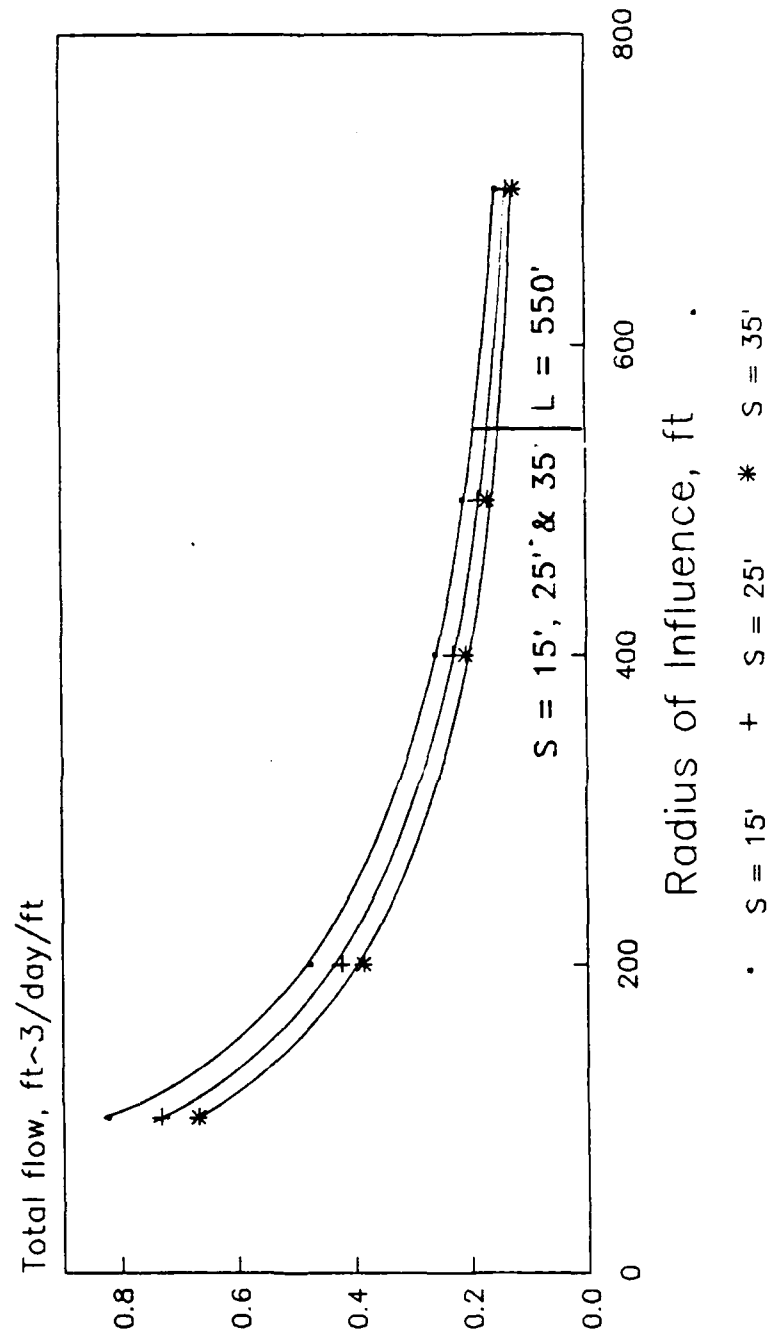


Fig. 2-2
Determination of radius of influence
 S = Spacing, L = Radius of Influence

Radius of Influence

(Slope = 0%, $H = 60'$, $h = 10'$)

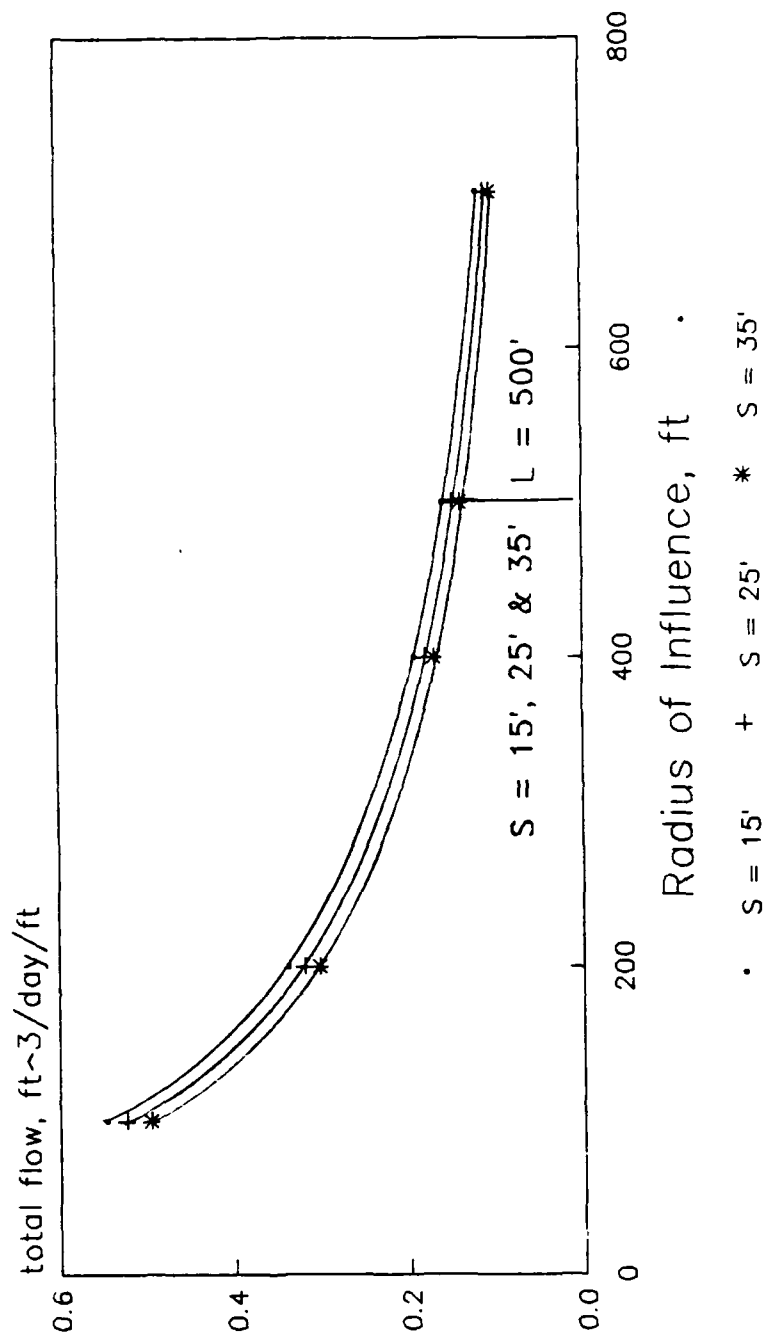


Fig. 2-3
Determination of radius of influence
 S = Spacing, L = Radius of Influence

Radius of Influence

(Slope = 0%, $H = 60'$, $h = 20'$)

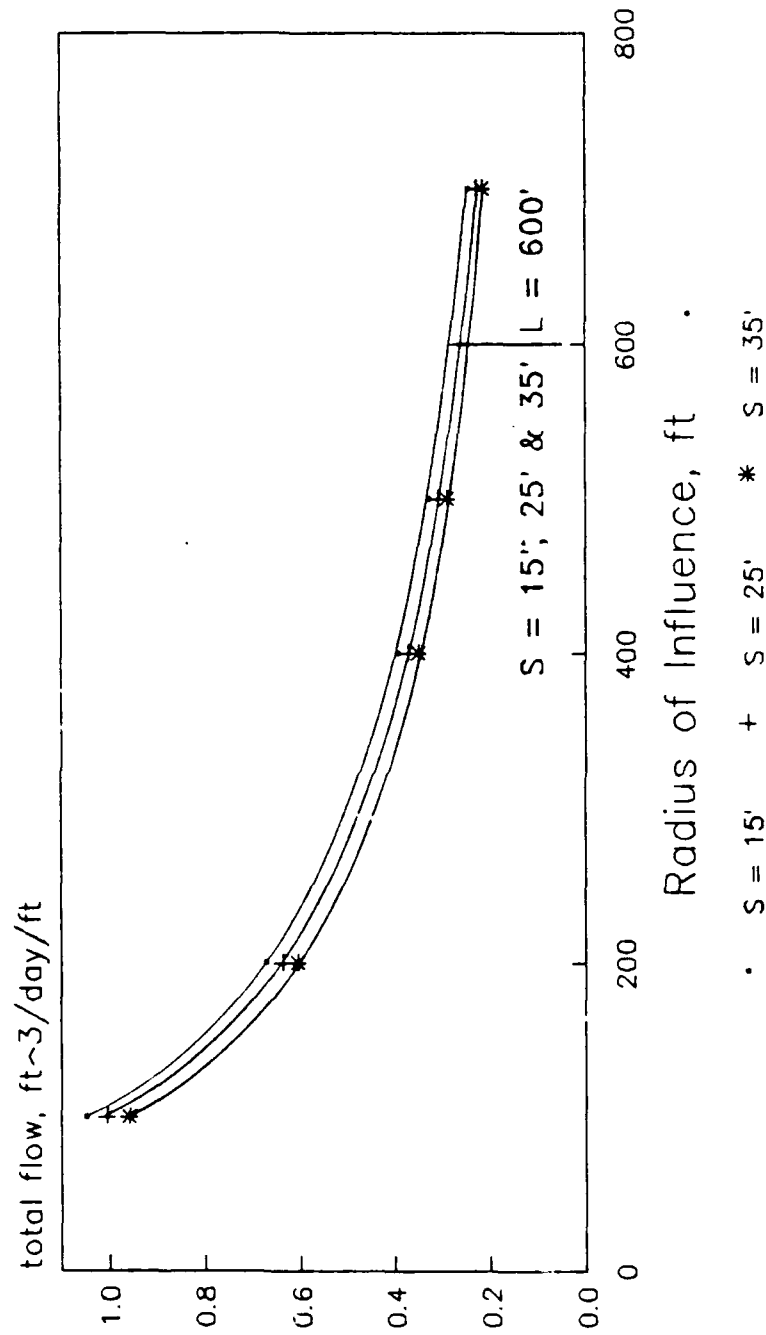


Fig. 2-4
Determination of radius of influence
 $S =$ Spacing, $L =$ Radius of Influence

Radius of Influence

(Slope = 3.5%, H = 20', h = 10')

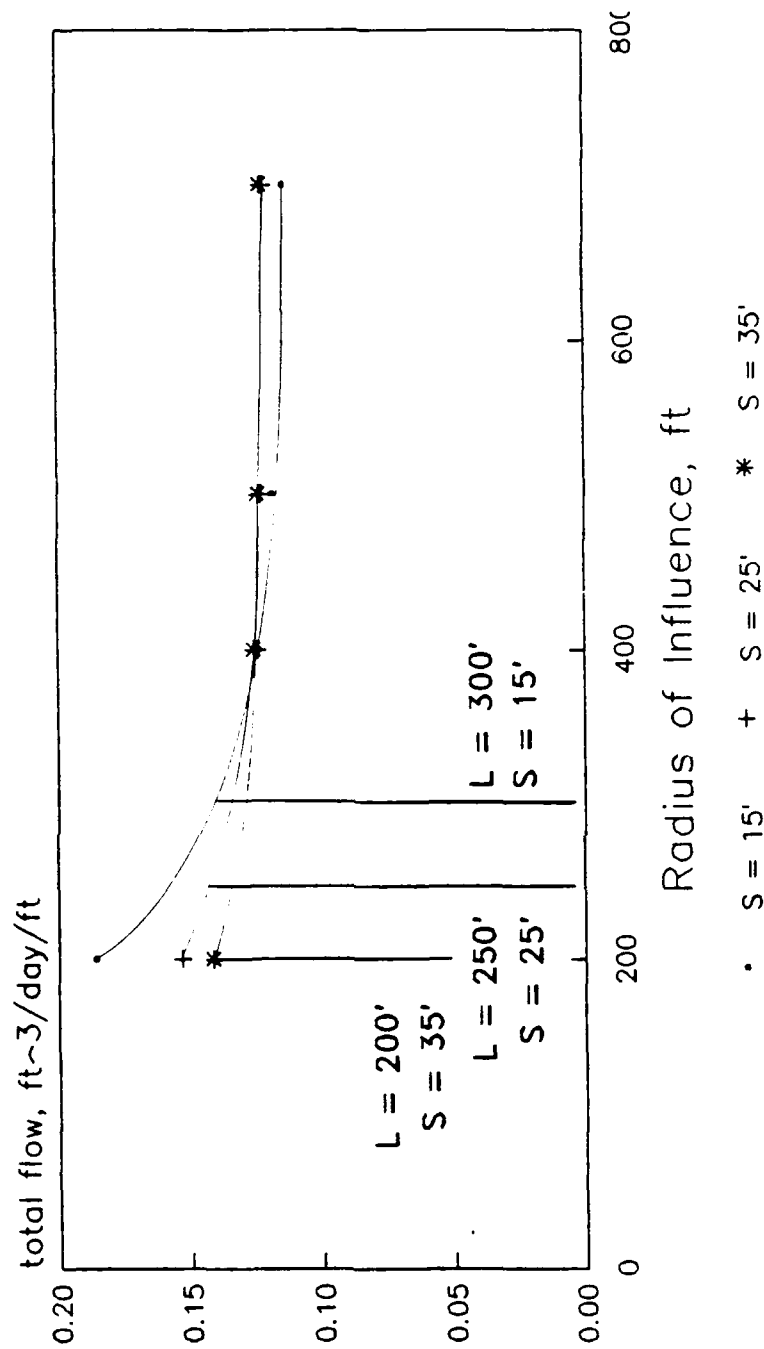


Fig. 2-5
Determination of radius of influence
S= Spacing, L= Radius of Influence

Radius of Influence

(Slope = 3.5%, H = 20', h = 20')

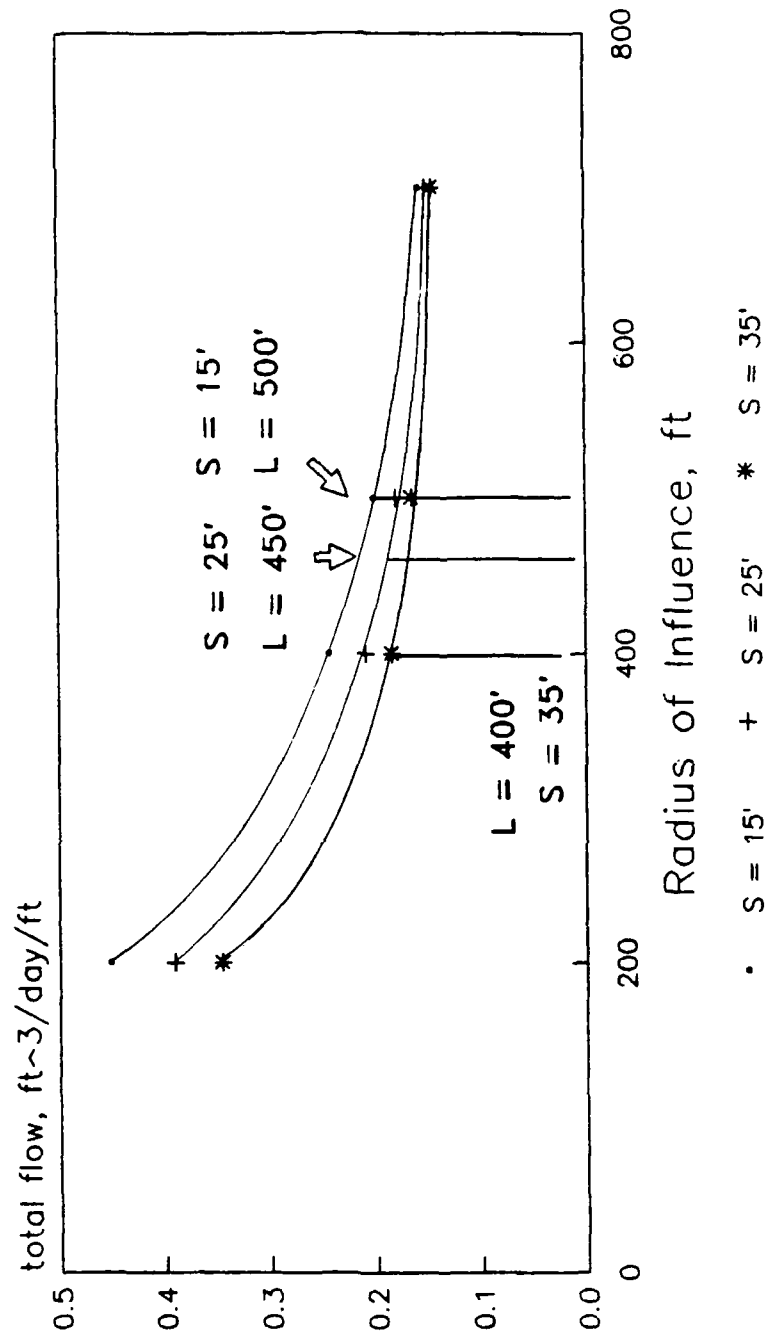


Fig. 2-6
Determination of radius of influence
S= Spacing, L= Radius of Influence

Radius of Influence

(Slope = 3.5%, H = 60', h = 10')

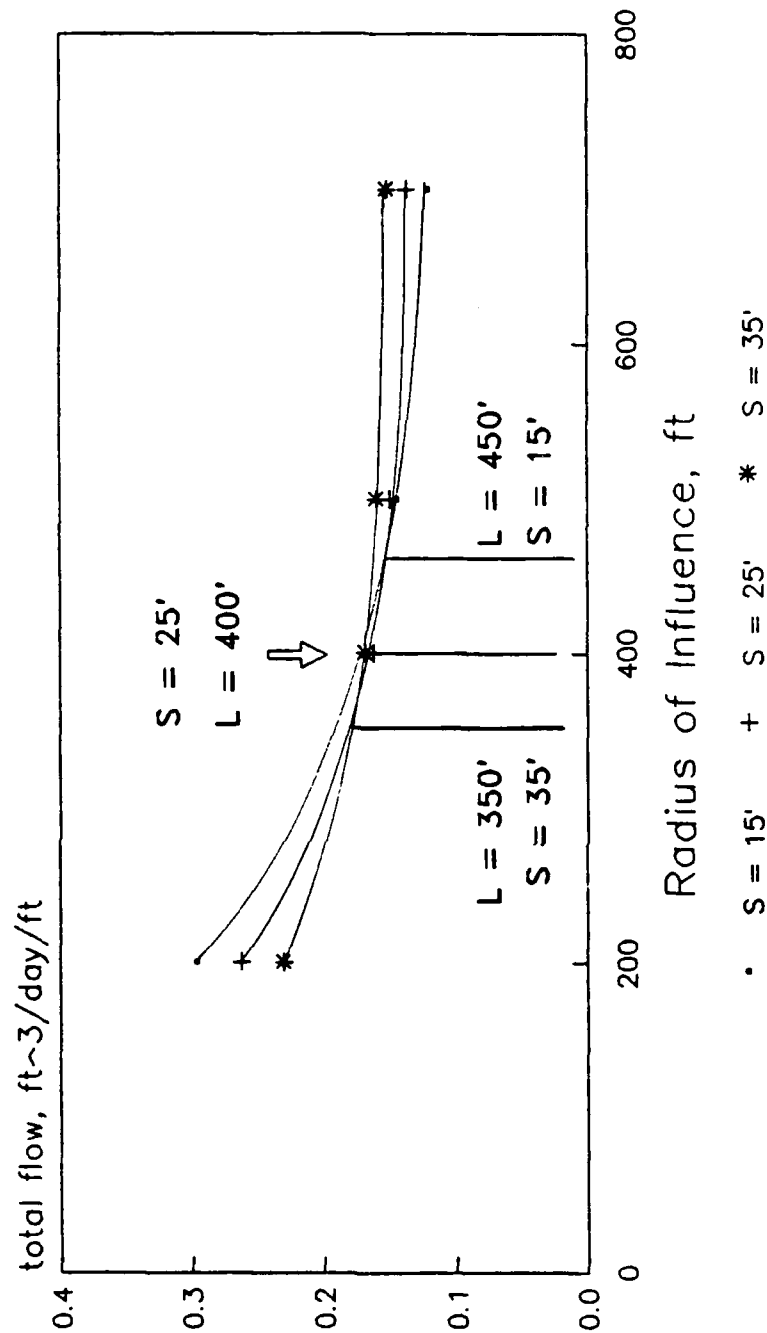


Fig. 2-7
Determination of radius of influence
S = Spacing, L = Radius of Influence

Radius of Influence

(Slope = 3.5%, H = 60', h = 20')

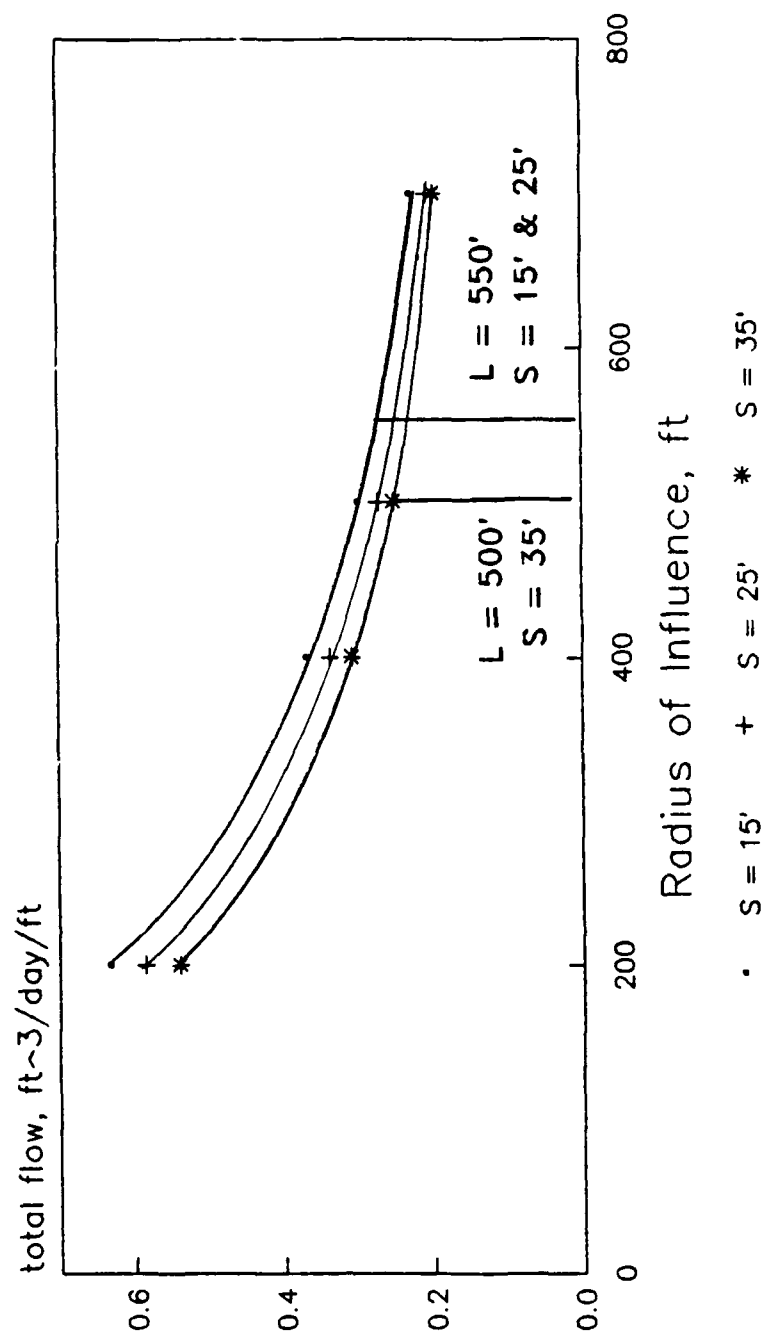


Fig. 2-8
Determination of radius of influence
S= Spacing, L= Radius of Influence

Radius of Influence

(Slope = 7%, H = 20', h = 10')

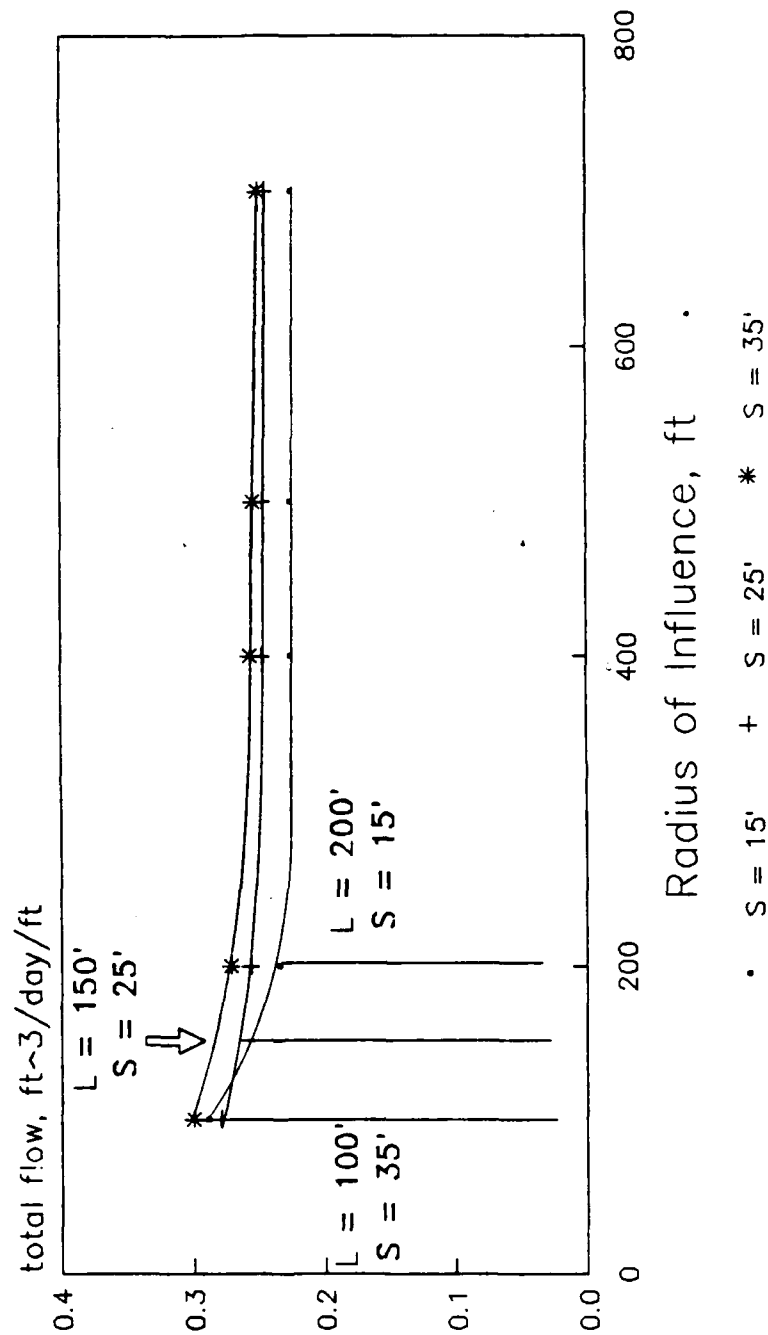


Fig. 2-9
Determination of radius of influence
S = Spacing, L = Radius of Influence

Radius of Influence

(Slope = 7%, $H = 20'$, $h = 20'$)

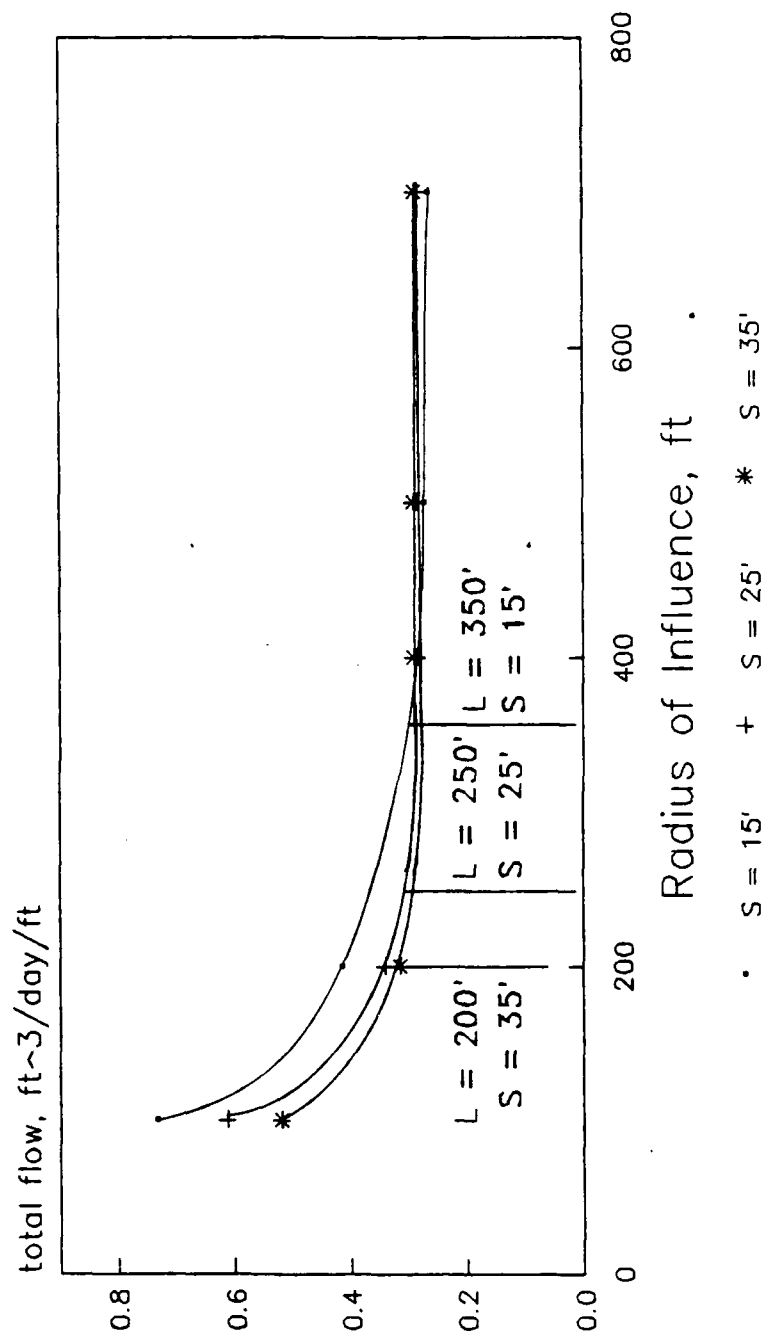


Fig. 2-10
Determination of radius of influence
S = Spacing, L = Radius of Influence

Radius of Influence

(Slope = 7%, $H = 60'$, $h = 10'$)

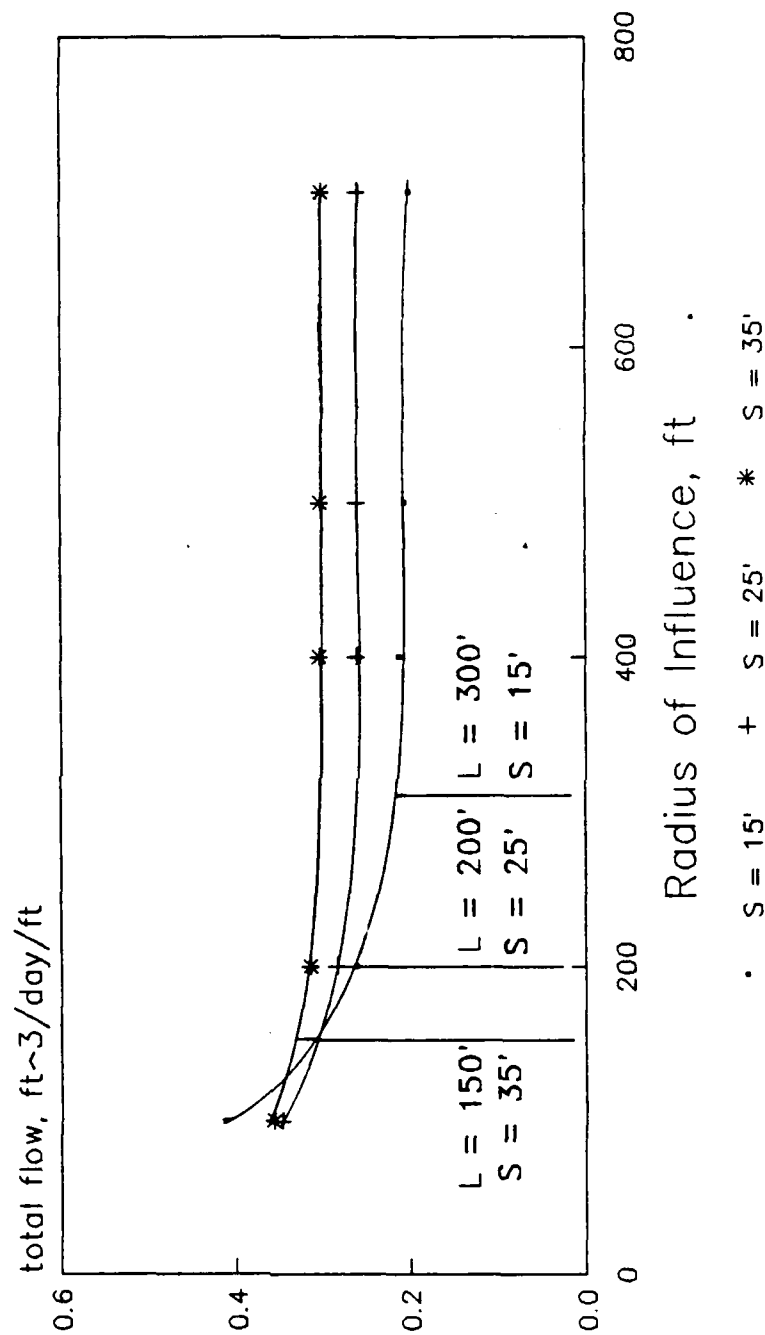


Fig. 2-11
Determination of radius of influence
S = Spacing, L = Radius of Influence

Radius of Influence

(Slope = 7%, H = 60', h = 20')

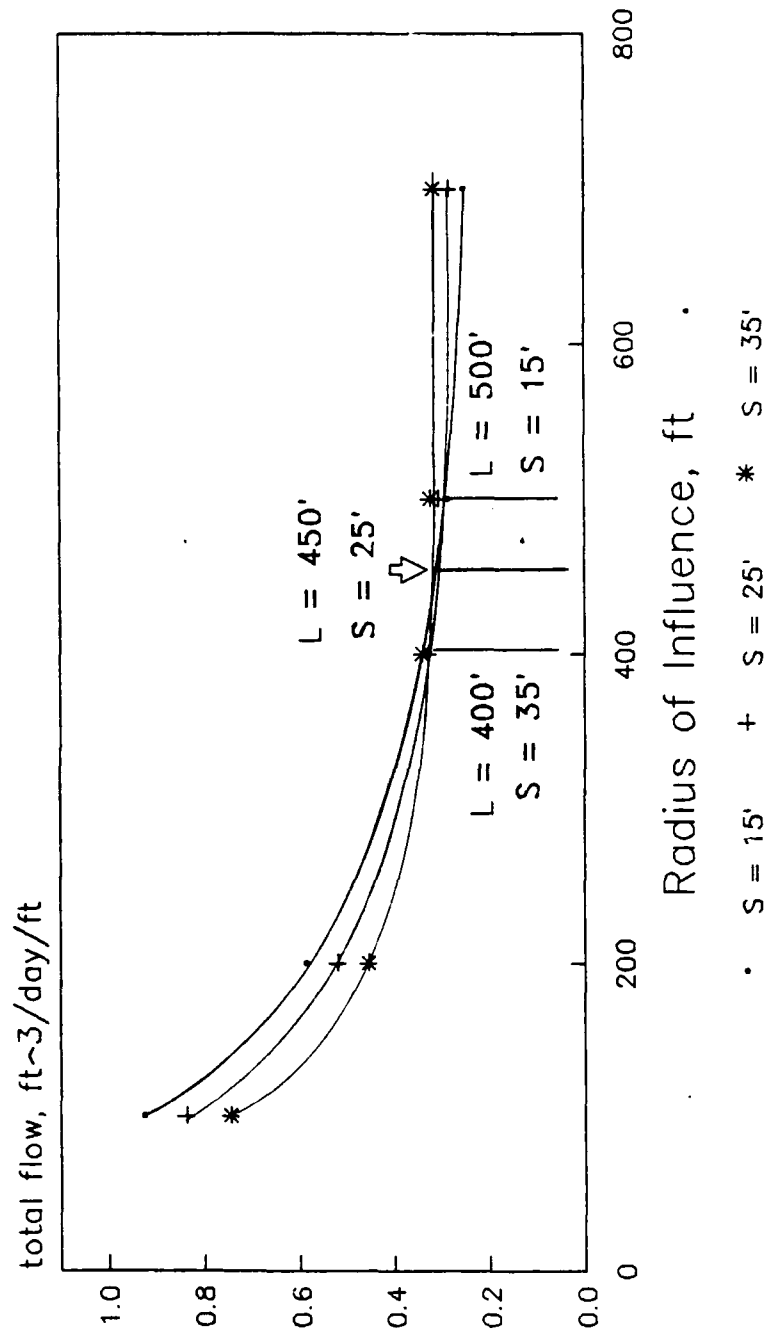


Fig. 2-12
Determination of radius of influence
S = Spacing, L = Radius of Influence

IV. Using Aral Seepage Program:

The Aral Seepage Program, a finite element model program was used in the evaluation of drainage characteristics of trench drain systems. An excellent program user's manual is included in an earlier study (Pirtle, Appendix A). Used for confined and unconfined flow problems of axisymmetric or two dimensional seepage, the program is available at Georgia Institute of Technology, Department of Civil Engineering.

The user inputs the problem geometry, soil characteristics and position of ground water. By equilibrium solutions to the discrete grid elements the program adjusts the initially assumed free surface through several iterations until the level of accuracy is satisfied. When completed a solution is presented to the defined problem, including total seepage flow through seepage faces and the steady state free water surface.

The referenced user's manual includes detailed sample input for an unconfined seepage problem. The evaluated trench drain system is of the same nature and so input was extremely similar. Appendix B of this study is a copy of an input data file for a run of the Aral Seepage Program for a trench drain. Figure 3-5 of Chapter 3 will provide node and element numbers as used.

Comments on the Aral Seepage Program User's Manual:

1. The user's manual does not provide guidance in setting the model sensitivity on the Title and Type Problem Card (card FERR). This card sets the degree of accuracy which will discontinue iterations of the free surface calculations. A precise number is not as important as maintaining a minimum number of iterations during the run. Recommended accuracy will be a value such that a minimum of three iterations are completed in the free surface calculations. The necessary value of sensitivity will become evident after several runs.

2. The control card input for NNPC, total number of corner nodal points, makes it clear that intermediate nodes will be generated between the listed corner nodes. What is not clear is that it is recommended that a line of elements several rows below the free water surface, should be defined as corner nodes. This establishment of an unmoving row close to the free surface reduces the iteration time. Iterations occur between the intermediate nodes and the free water surface. Figure 3-5 is a sample of the finite element mesh used in this study.

The Free Surface Nodal Cards include the top and bottom corner nodes of the "movable zone" described above. Sixteen corner nodes, or eight sets of free surface and base, are allowed for each card.

3. General program notes not included in the user's manual:

-The current version of the Aral Seepage Program is limited to thirty columns of elements.

-The total number of seepage faces with Dirichlet boundaries is not necessarily one less than the total number of Dirichlet Boundary faces. In the trench drain problem six boundary faces exist with only four drainage faces. In a problem done by symmetry there would be one less seepage face than the number of Dirichlet boundaries.

4. The output from the Aral Seepage Program is extremely straight forward with only one area of confusion. Appendix B of this study includes a copy of a printout result from the study. Under the "New coordinates of the Free Surface Line" there are several iterations of free surface corner nodal points and the x and y coordinates. The last iteration is the free surface calculated within the desired accuracy. A plot of the listed x and y coordinates is a cross section of the free water level. The maximum free surface elevation between trenches is the maximum value between any of the four trench drains. In Chapter 3 the selection of this value is reviewed. The last page of the output contains

the total seepage flow. The area of confusion comes from the presence of seepage output between trenches, across element faces not defined as seepage faces. Those output figures are not correct. Using the nodal address numbers from the bottom of the trench (Fig. 3-5) the actual seepage output at each trench can be obtained. To find the total flow the sum of trench flows is calculated manually as the listed total flow reflects the imaginary outflow between trench faces.

V. Evaluation:

In the analysis of the trench drain system dimensionless products will be used to prepare presentations of the affect of the many changing variables upon which the solution is dependent. The key variable is the radius of influence which will be determined by solving each model for several different radii and selecting the correct value by interpolation. Finally in the future use of the Aral Seepage Program several notes can be used to augment the existing user's manual.

CHAPTER 3

INPUT AND OUTPUT OF THE TRENCH DRAIN EVALUATION

I. Introduction:

The evaluation of different variables in a foundation trench drain involves a significant amount of input and output data. It is extremely important that methodical presentation and collection of data be practiced. This chapter details the system, under which all variables were considered. The approach used insured that the entire range under consideration was evaluated.

II. Problem Geometry:

In evaluating the dewatering trench drain systems the geometry must be established. Among the many variables in such an evaluation are the vertical and horizontal hydraulic conductivities of the soil, number of trenches in the system and width of the trench. To simplify the problem the above variables were held constant in this study.

Other variables in an evaluation are spacing between drains, thickness of the aquifer, free head above drains and slope of the aquifer. These factors were varied in this study over ranges sufficient to determine the characteristics of the system under as normally used.

Confined flow was not considered in this study and each case was for a water table aquifer. A confined aquifer cannot be dewatered effectively with an open pumping or sump method

((a)Powers, pg 114). A significant assumption of phraetic flow, included in the finite element analysis, provides the radius of influence of drawdown.

A primary concern in dewatering a water table aquifer is the storage depletion ((c)Powers, pg.3). This study concerns trench drains under steady state conditions following construction. In steady state, the storage has been depleted and will not contribute additional flow.

The previous study (Pirtle) was conducted under symmetry as a half space problem with no slope. The finite element method in a half space works very well until a sloping aquifer is considered. Use of symmetry permits evaluating one half of the problem, doubling the results accurately models the full problem. To do this with a sloping aquifer models a perched water table. Figures 3-1 and 3-2 represents one half of a system under symmetry and a full system respectively.

For this study the affects of a sloping aquifer were essential, and a full width model was required. Figure 3-3 is a representation of the cross section of the sloping aquifer. In the full width model the free water surface both upstream and downstream of the foundation trench drain must be evaluated. Figure 3-4 is a cross section of the problem with the assigned variable names.

In the model four trench drains were selected. Although this models a relatively small foundation it should yield results which may be used conservatively for larger

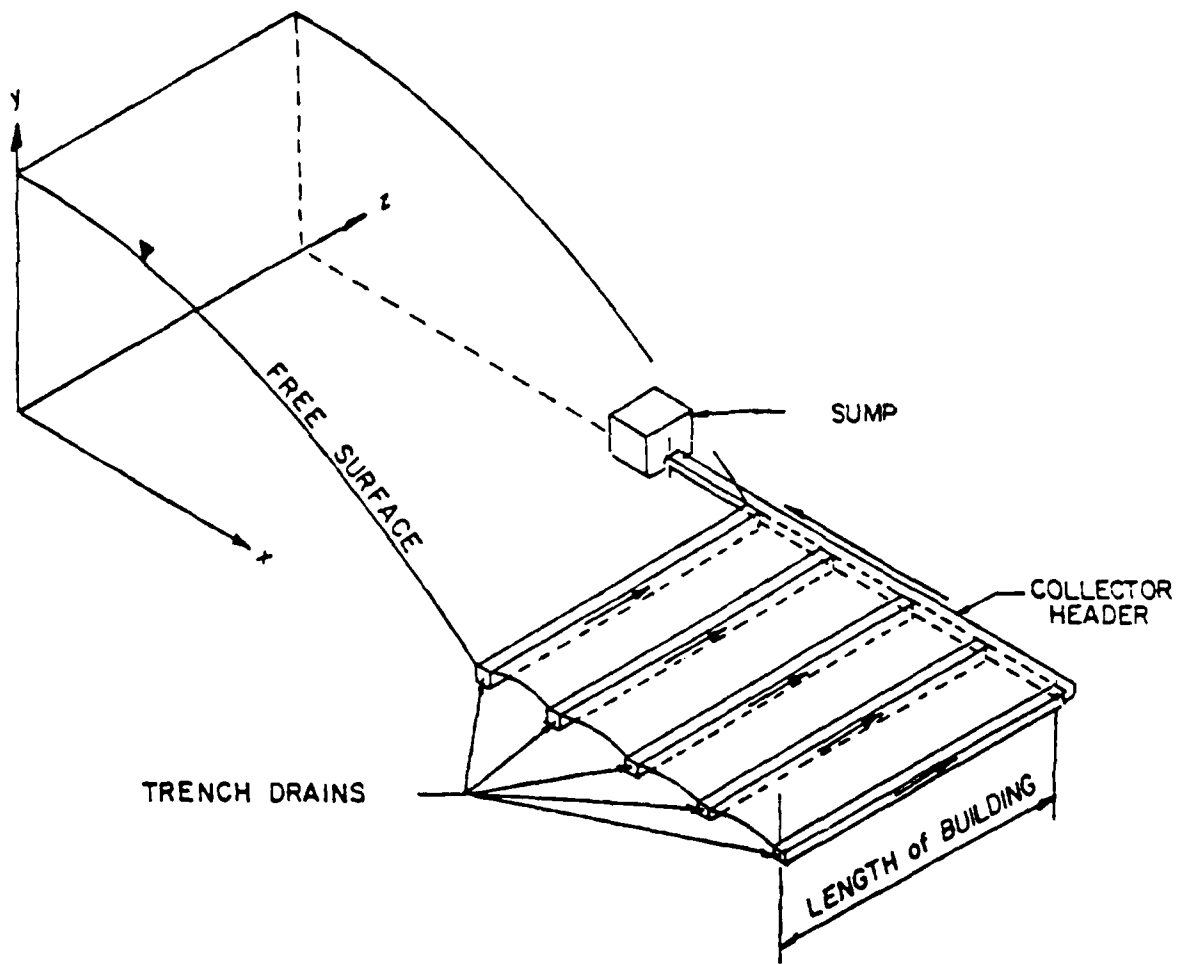


Fig. 3-1 Underdrain System in Half Space
(after Pirtle)

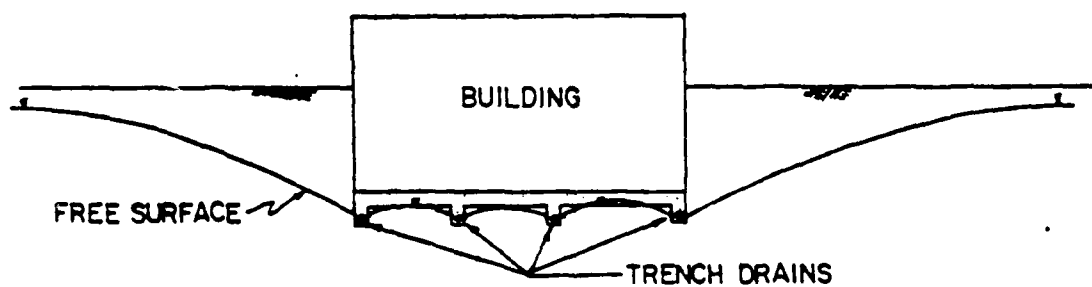


Fig. 3-2 Typical application of Trench Drain
(after Pirtle)

TRENCH DRAIN SYSTEM

Profile

($L_d = 200'$, slope 3.5 %)

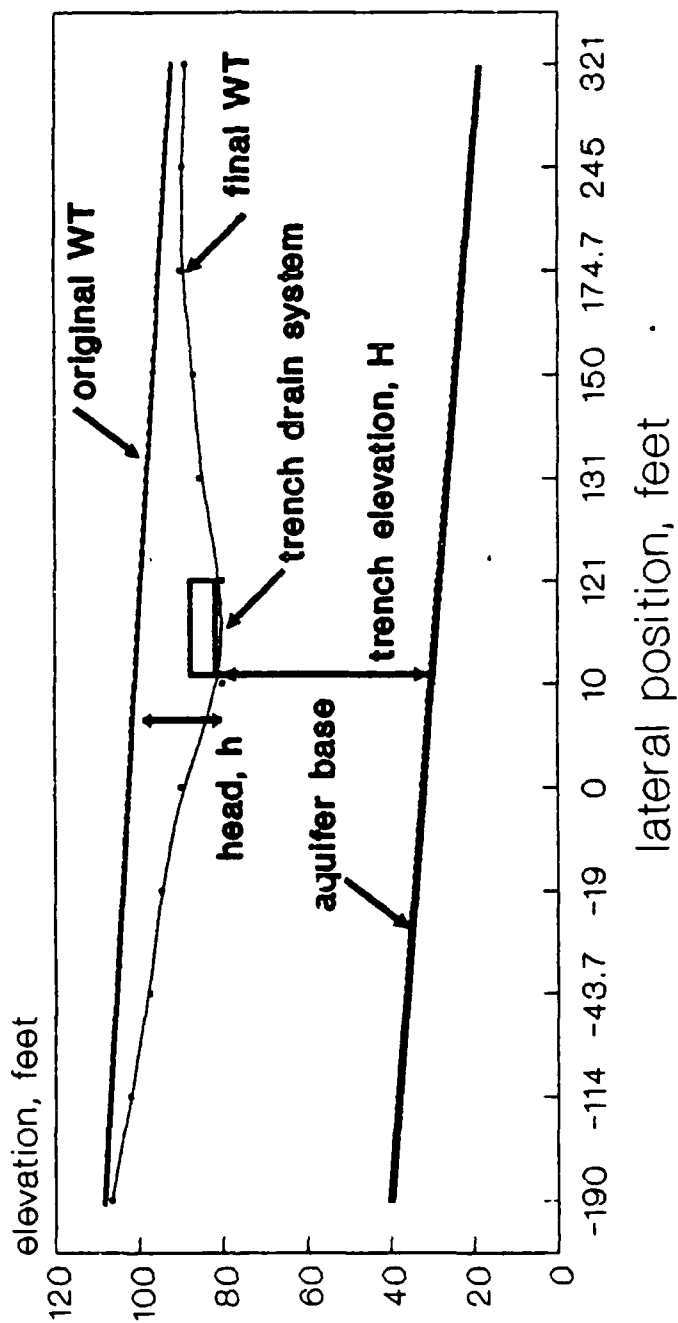


Fig. 3-3
Typical cross section of trench drain
system with original aquifer boundaries

CROSS SECTION

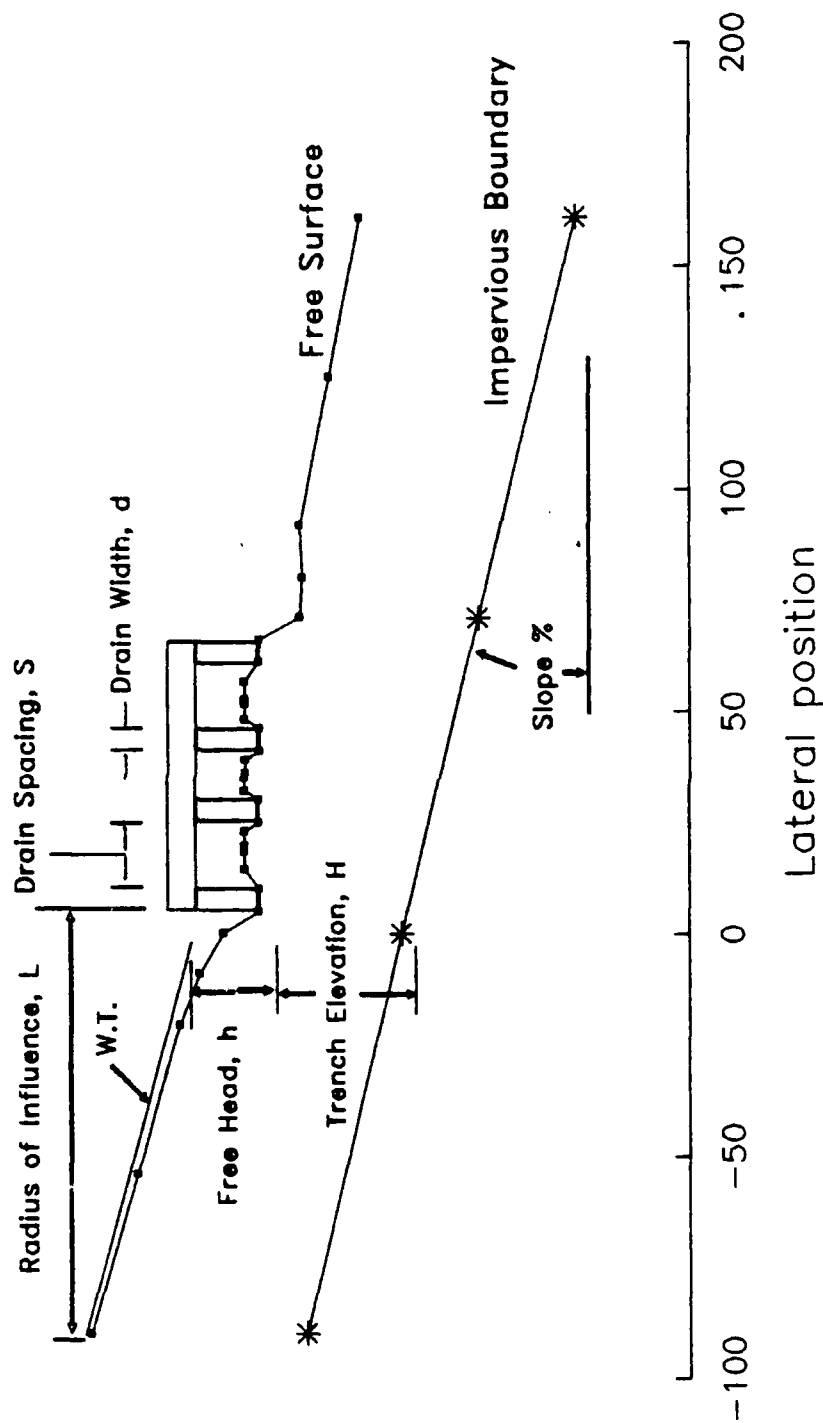


Fig. 3-4
Variables of Trench Drain Analysis

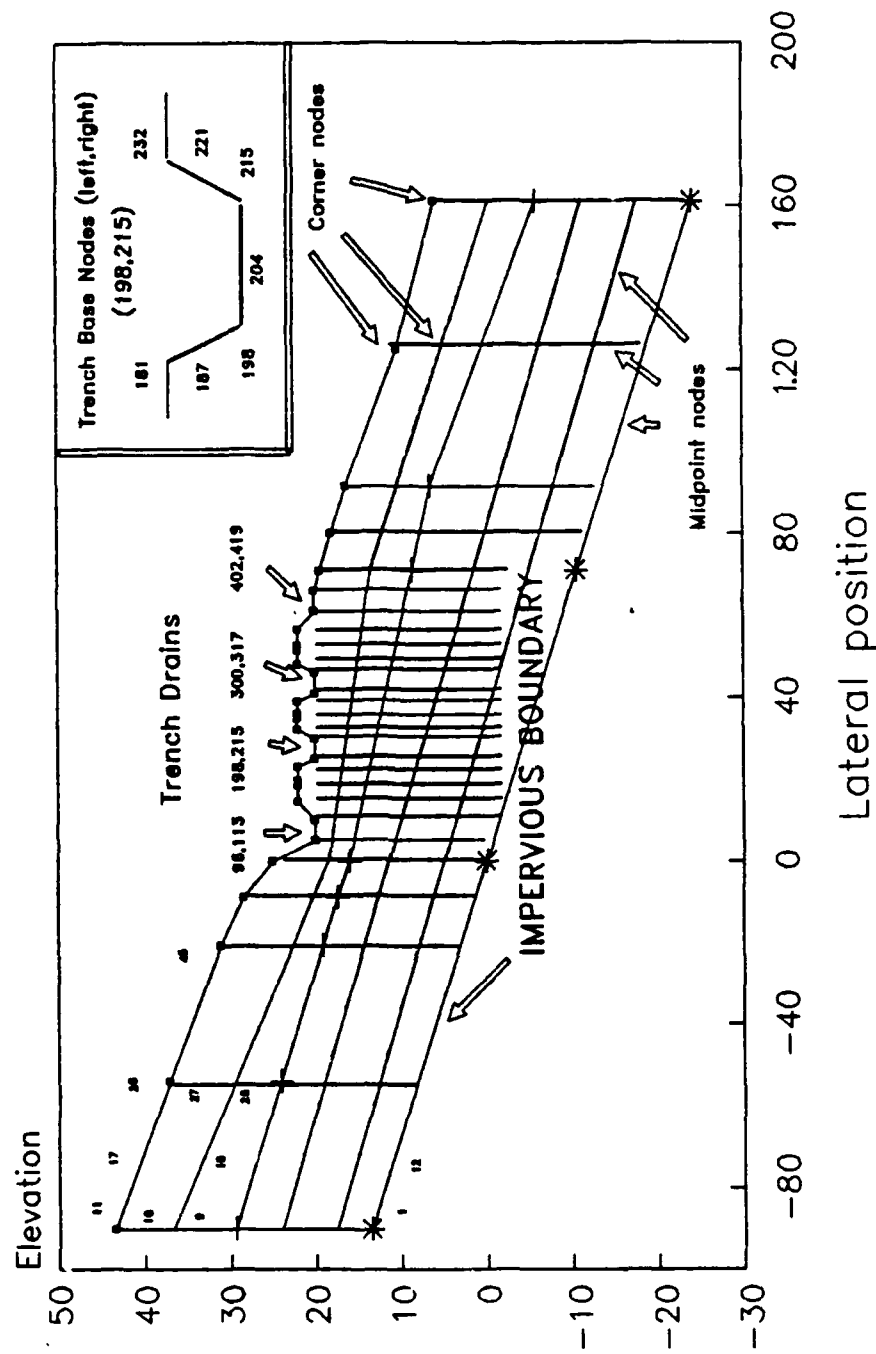


Fig. 3-5
Example Mesh Used

foundations. Generally in a sloping aquifer the majority of dewatering and the maximum free surface between trenches occur due to the outboard drain. For a sloping aquifer this model will closely model even a large foundation as most of the removed water is into the upstream trench. The number of drains might be a prime area for future study.

The width of the drainage trenches were held at one and one half feet wide. While the earlier study (Pirtle, Chap 4) showed total flow to vary with drain width, it is reasonable to select a single, typical value. The use of 1.5 feet is based on the approximate width of a normal backhoe bucket.

The horizontal hydraulic conductivity (permeability, k_h) was selected as a constant $0.2 \text{ ft}^2/\text{day}/\text{ft}$ which is, $7 \times 10^{-5} \text{ cm}/\text{sec}$. This is the normal permeability of a silty sand ((b)Cedergren, pg 34), common to the Atlanta area.

For the vertical hydraulic conductivity (K_v) the same $0.2 \text{ ft}^2/\text{day}/\text{ft}$ was used. While a reasonable value, it does not reflect the normal condition of a greater horizontal hydraulic conductivity, which may be greater than the vertical by a multiple of three to ten times ((a)Powers, pg.92). It would be an excellent study to evaluate the affects of anisotropy in the trench drain system.

The primary area of concern in this study were the affects of a sloping aquifer. To consider a complete range, three slopes considered. Initially 0%, 7% and 15% slopes were selected. The aquifer thickness remains the same through the

area of consideration with a uniform aquifer base and water table slope. Once the study was begun it became apparent that the 15% slope was too severe. The study was modified with 7% the maximum slope considered and additional data was collected for a 3.5% slope.

Trench drain spacing was evaluated using 15 feet, 25 feet and 35 feet. For the assumed four drain system this allows consideration of a foundation from 60 to 120 feet wide. In actual practice the trench drains are excavated between the column lines so normal spacing is that of the column spacing. The results for a model with trench spacing of 25 and 35 feet are most likely to be used.

An assumption for this study was that the aquifer remain of constant thickness across the entire area of water table depression. For some models this area is 1000 feet across. It is certainly not a normal soil condition for the aquifer to be so uniform. In general the area of depression is significantly smaller than the above value. Assuming uniform thickness for distances of 300 and 400 feet is reasonable.

To separate the affects of free head from thickness of aquifer the later was considered as two components. The first component was thickness below the drain or trench elevation (H) and the second was free head above drain (h). The sum of the two components is the total aquifer thickness.

To bracket normal conditions in the evaluation of trench drains a maximum aquifer thickness of 80 feet was used. While

arbitrary this value is reasonable in an aquifer at the surface. The minimum aquifer thickness used was 30 feet. Certainly smaller aquifers exist at the ground surface but, a trench drain would probably not be as effective as a cutoff wall in protecting the foundation for such a shallow depth.

The last variable considered in the study was the free head of aquifer above the bottom of the trench drain. As described above the free head is a component of the aquifer thickness. Free head was held at a maximum of 20 feet. As the free head increases the amount of water removed must also increase. Under an open draining trench system the radius of influence is much larger and interference with other structures is a problem. As a free head of 20 feet is approached alternative dewatering methods may have to be considered.

The minimum free head considered was ten feet. This value was selected arbitrarily. The foundation trench system would work very well for a smaller free head. In retrospect the minimum head considered should have been five feet. Less free head and the necessary trench depth would be so small that a blanket drain would be more economical. A comparison of the two drain systems will be undertaken on an economics basis in Chapter 4.

III. Naming and numbering convention:

As a shorthand means of identifying the variables (Figure 3-4) of this study each is named as follows:

Radius of influence, L

Total flow, q

Aquifer slope, p

Trench spacing, S

Trench elevation, H

Free head above trench, h

Maximum free surface height, F

Hydraulic conductivity (vertical), k_v

Hydraulic conductivity (horizontal), k_h

As described in Chapter 2 the determination of an accurate radius of influence involved four to six trial runs of a model. The result was 36 geometries and over 200 computer runs. In order to identify the geometry of each trial the data files and resultants were named from a file convention. An alpha-numeric name of six characters, with

each one have several values was used. The files were named and the data sorted as follows:

A12345.dat, where the .dat is a conventional suffix of the operating system

First Character (A)

Vertical hydraulic conductivity, k_v

$$A = 0.2 \text{ ft}^2/\text{day}/\text{ft}$$

Second Character (1)

Aquifer slope, g

$$0 = 0 \%$$

$$3 = 3.5 \%$$

$$7 = 7 \%$$

$$9 = 15 \%$$

Third Character (2)

Radius of influence, L

$$3 = 100 \text{ ft}$$

$$5 = 200 \text{ ft}$$

$$8 = 400 \text{ ft}$$

$$9 = 500 \text{ ft}$$

$$0 = 700 \text{ ft}$$

Fourth Character (3)

Trench spacing, S

$$3 = 15 \text{ ft}$$

$$5 = 25 \text{ ft}$$

$$7 = 35 \text{ ft}$$

Fifth Character (4)

Trench elevation, H

2 = 20 ft

6 = 60 ft

Sixth Character (5)

Free head, h

1 = 10 ft

2 = 20 ft

The above convention is used in this study in names of data files. If a collection of data is gathered so that each group has a constant trench elevation, H and free head, h the data groups will be referenced by AxxxHh. In this example if the H = 20 feet and h = 10 feet the data group will be Axxx21. The data files used in this study are included in Appendix D.

IV. Conduct of study:

The primary output of the finite element analysis used in this study were the total drainage outfall per lineal foot of trench drain system and the maximum free surface of groundwater between trench drains. As detailed in Chapter 2 the study first had to determine the radius of influence for each condition. From Figure 3-5 the elements of the finite element grid between can be observed. The width between trenches was divided into five spans. So at four nodes the iterative determination of the FEA program predicted an

ultimate final elevation. This was determined for every trial radius, L and the maximum node elevation observed was recorded. Figures 3-6 through 3-9 are profiles, in the trench area, of the represented free surface for several trial runs.

It was expected that the maximum free surface (F) would occur near the center of the trench spacing (S). In order to obtain an accurate maximum free surface, the nodes between drains were not evenly spaced. Instead, the distance between nodes were greater near the trenches. For each run the maximum free surface selected was that of the maximum nodal elevation. This is obviously not accurate in all cases. An interpreted maximum free surface (F) would increase many of the values used but, would not reduce any value. The anticipated difference in magnitude of maximum free surface (F) does not exceed 0.01 feet or 0.1 inch. This potential error is not significant.

A review of the maximum free surface value for the many different finite element analysis runs revealed that the maximum free surface (F) always occurred between the outer most trench and the second trench. In an aquifer with no slope the conditions surrounding the outer trench were the same for both sides. On a sloping aquifer the maximum free surface (F) was at the upstream side of the trench drain system.

With the maximum free surface available for every geometry of problem and every trial radius of influence there

FREE SURFACE PROFILE

Slope = 7%, $L = 200'$, Spacing = $25'$

$H = 20'$, $h = 20'$

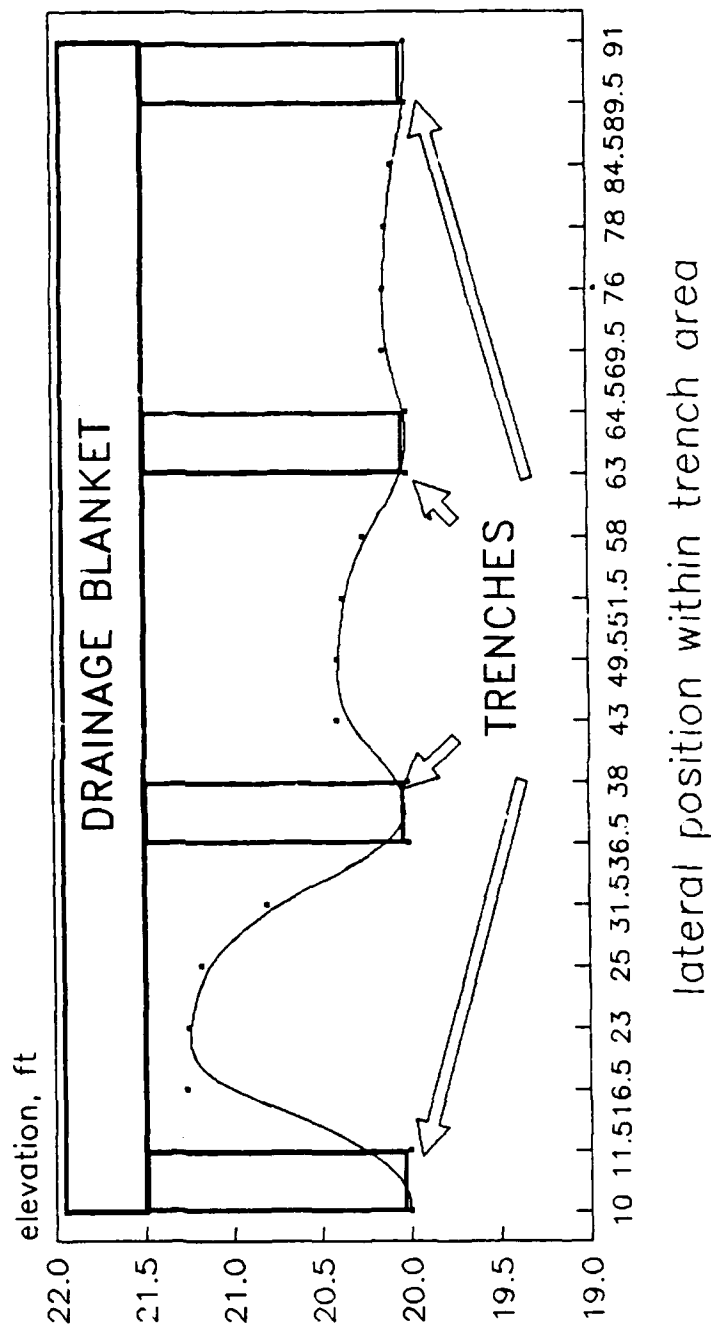
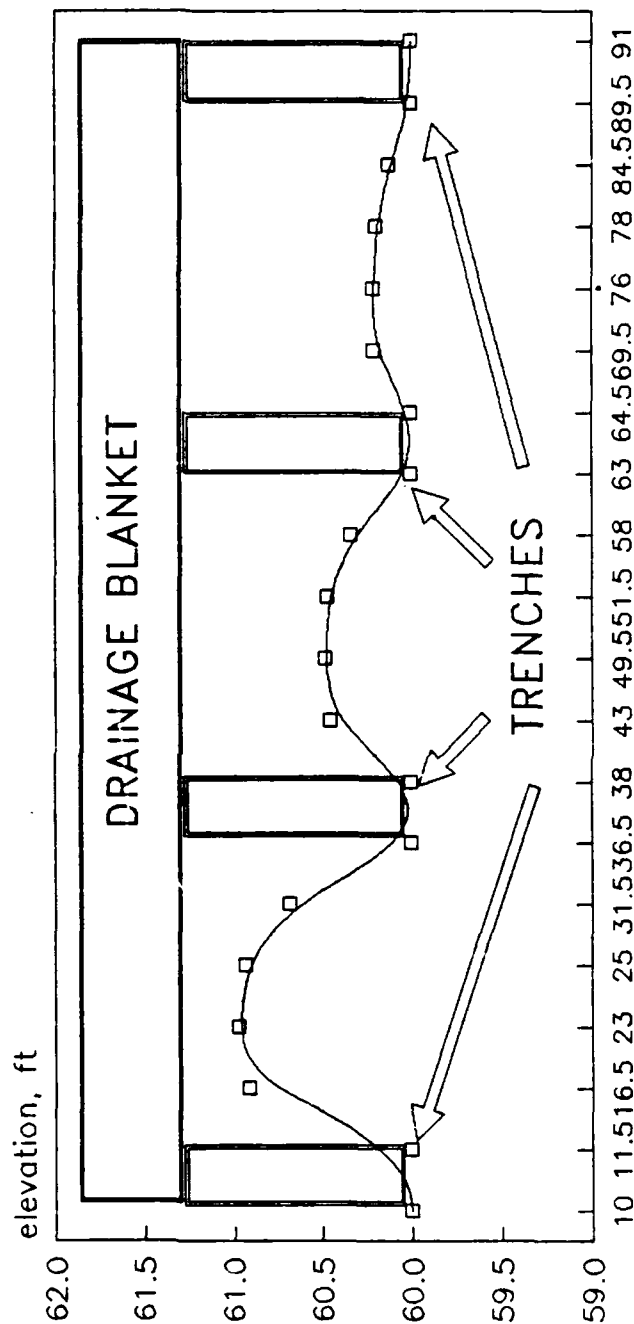


Fig. 3-6
Free surface between trenches

FREE SURFACE PROFILE

Slope = 3.5%, L = 700', Spacing = 25'

H = 60', h = 20'



lateral position within trench area

Fig. 3-7
Free surface between trenches

FREE SURFACE PROFILE

Slope = 3.5%, L = 400', Spacing = 25'

H = 60', h = 10'

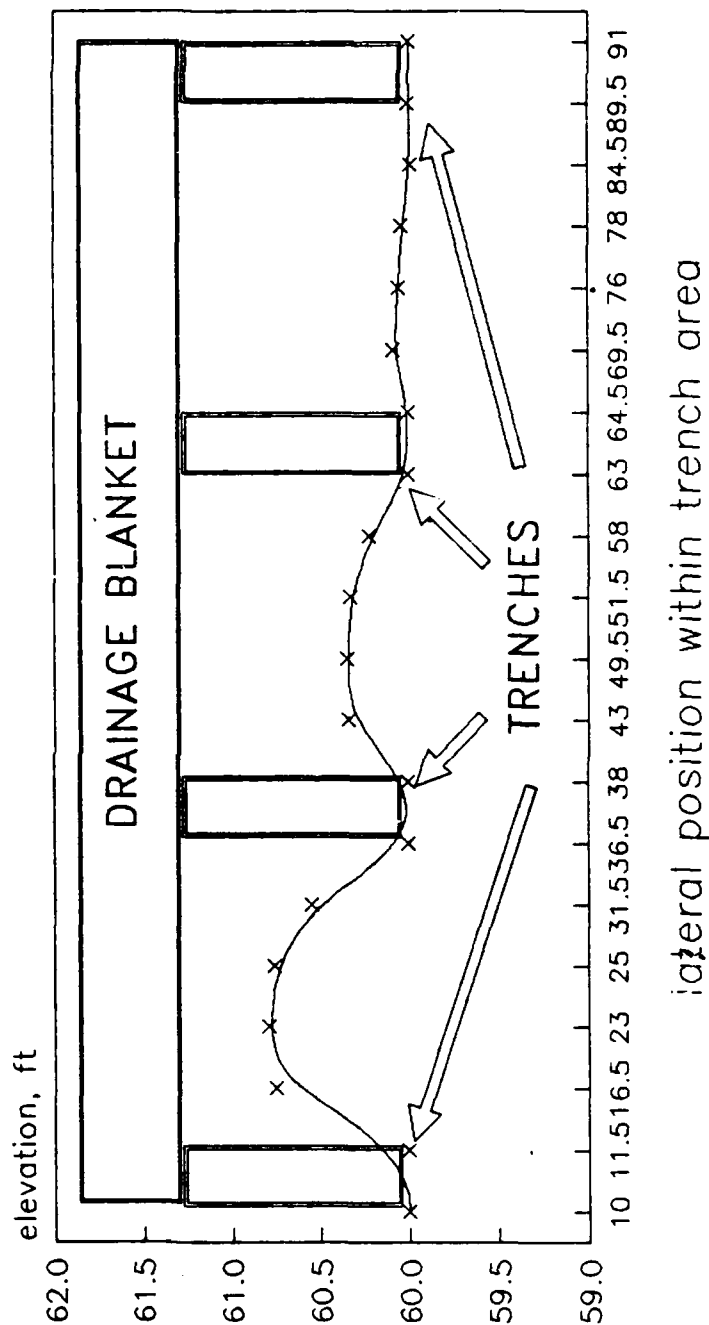


Fig. 3-8
Free surface between trenches

FREE SURFACE PROFILE

Slope = 3.5%, $L = 200'$, Spacing = 25'

$H = 20'$, $h = 20'$

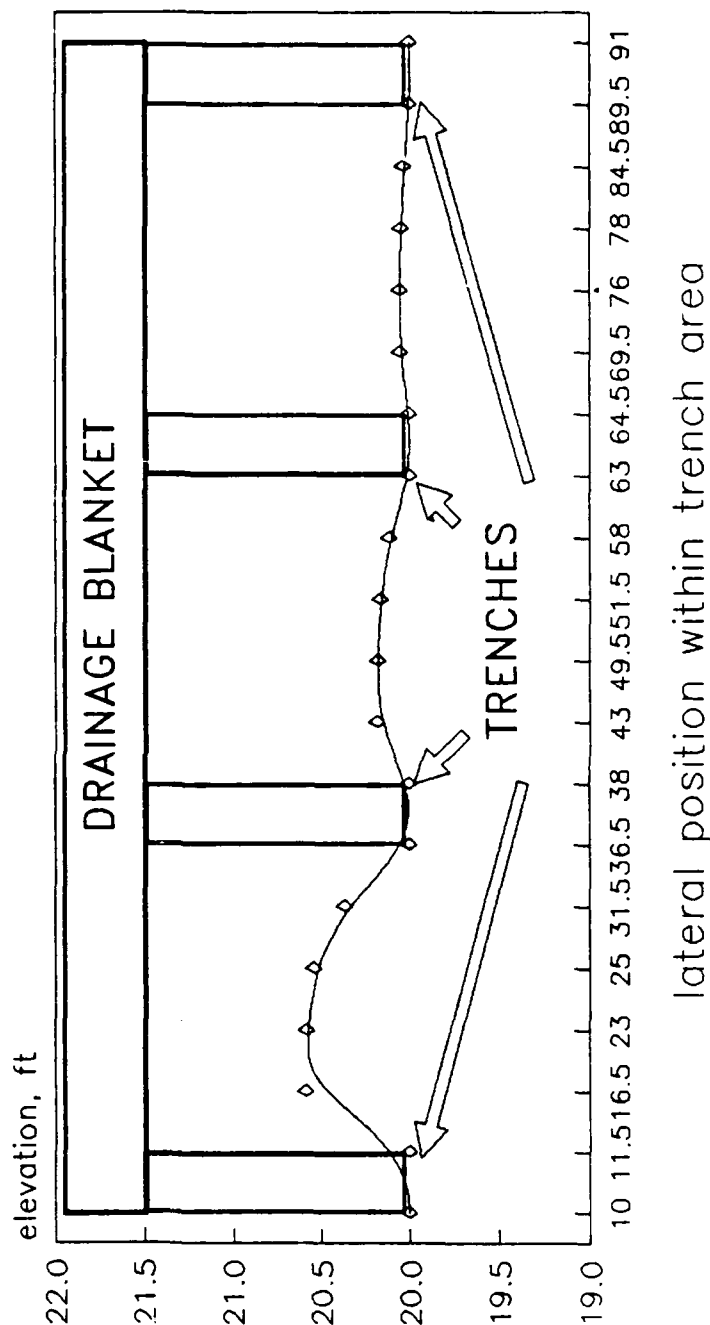


Fig. 3-9
Free surface between trenches

remained the evaluation of the maximum free surface (F) at the theoretically correct radius of influence. Fortunately from Figures 3-10 through 3-21 it is obvious that the maximum free surface varies with trial radius of influence in a consistent manner. As the theoretically correct radius of influence (L) is known from Chapter 2, the maximum free surface can be scaled from Figures 3-10 through 3-21. By convention the interpolation of data to evaluate the radius of influence used only values which were multiples of 50 feet.

The definition of a theoretically correct radius of influence at the distance of unchanging total flow defines the radius from the known phraetic nature of the problem. The unchanging flow also quantifies the total flow expected from the system. For this problem total flow was done per unit of width, making this a two dimensional problem.

The total flow, the maximum free surface and the radius of influence for each geometry of problem are now available. Analysis of trench drain systems were done with this data.

MAXIMUM FREE SURFACE

(Slope 0%, $H = 20'$, $h = 10'$)

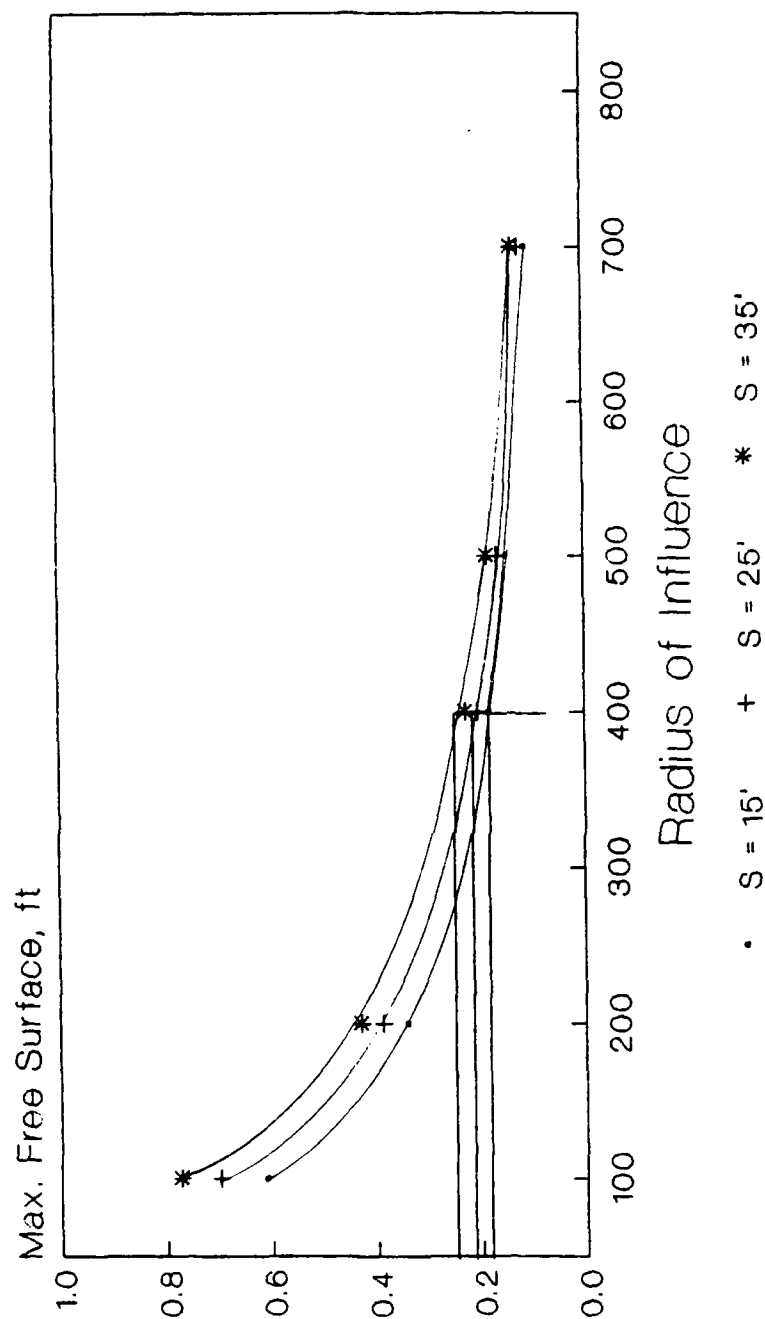


Fig. 3-10
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 0%, $H = 20'$, $h = 20'$)

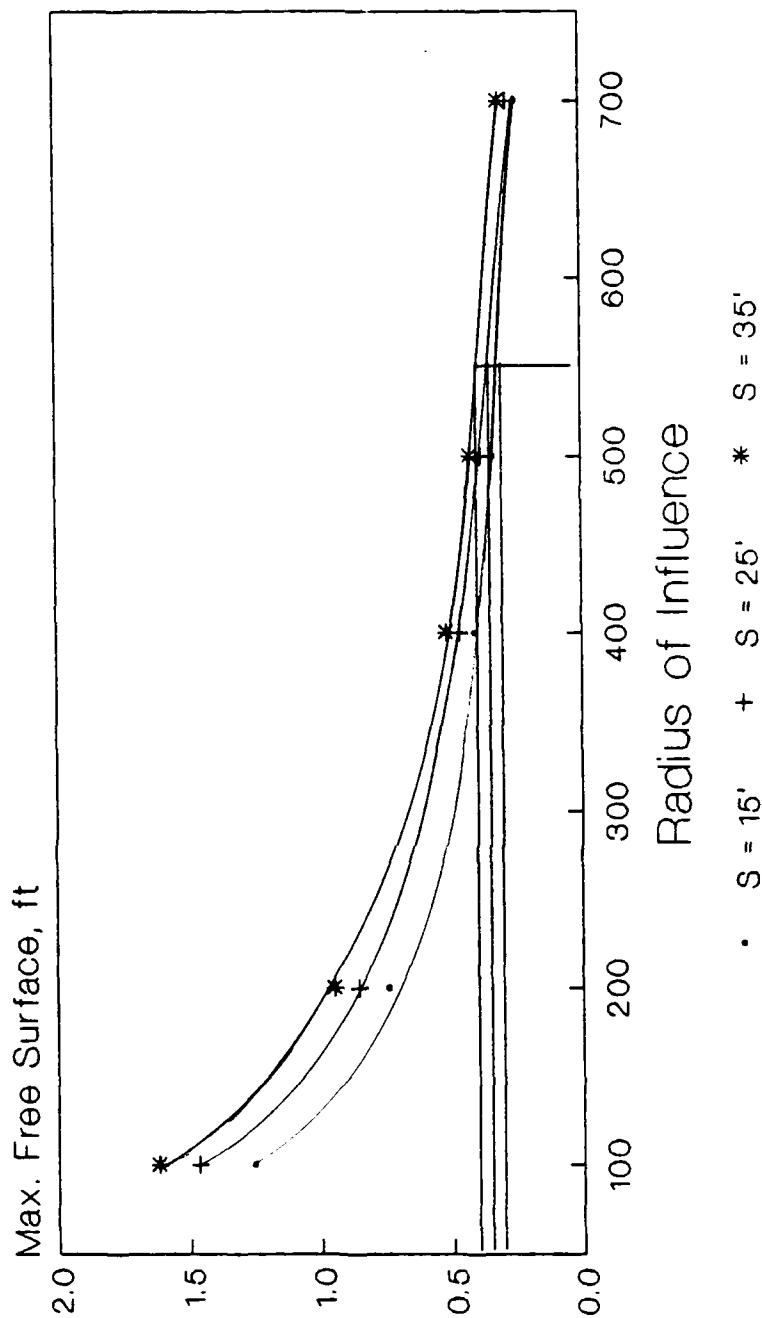


Fig. 3-11
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 0%, $H = 60'$, $h = 10'$)

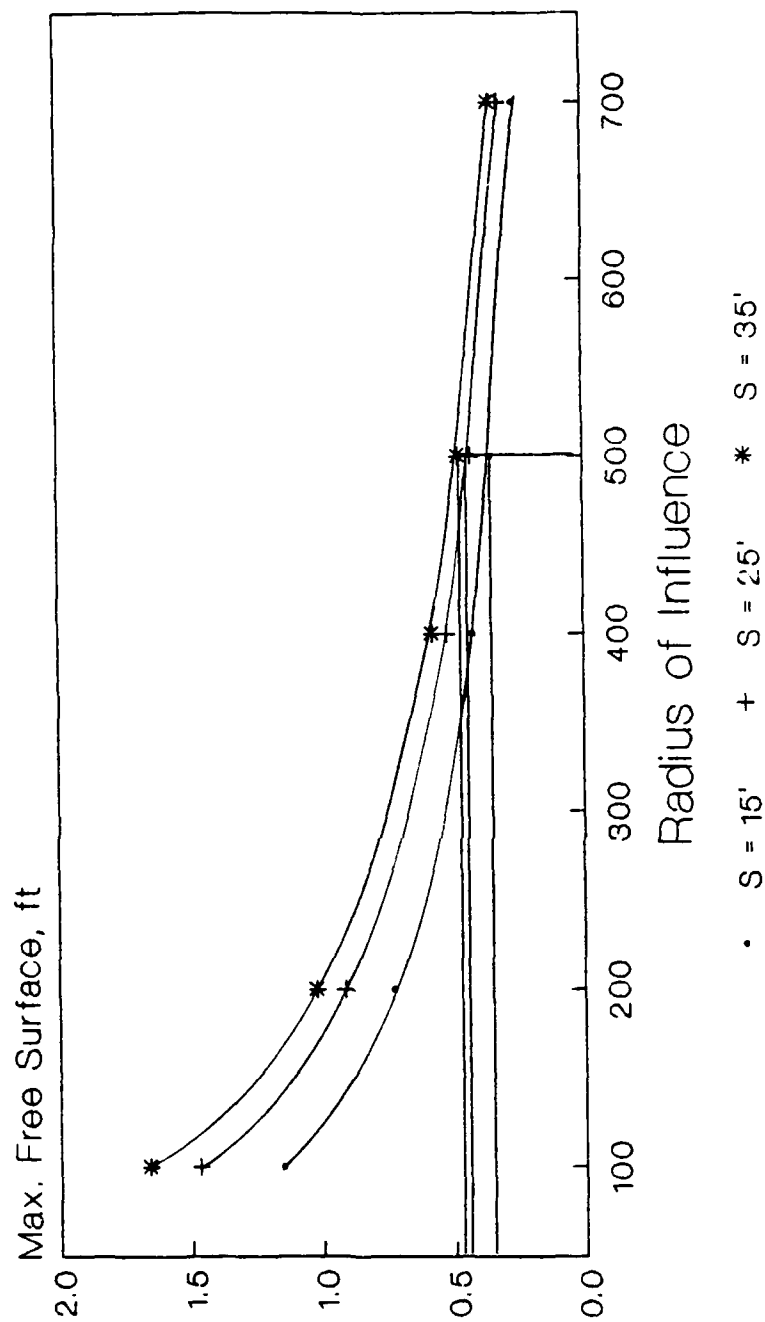


Fig. 3-12
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 0%, $H = 60'$, $h = 20'$)

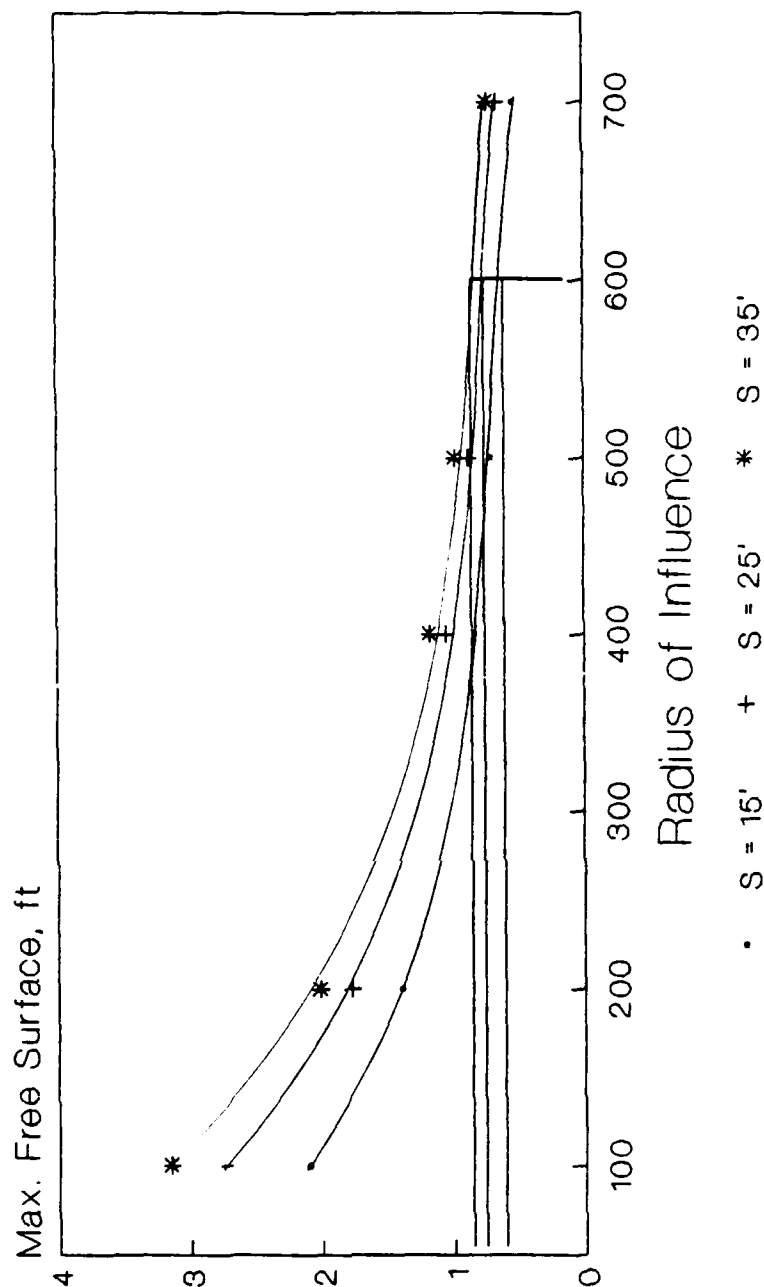


Fig. 3-13
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 3.5%, $H = 20'$, $h = 10'$)

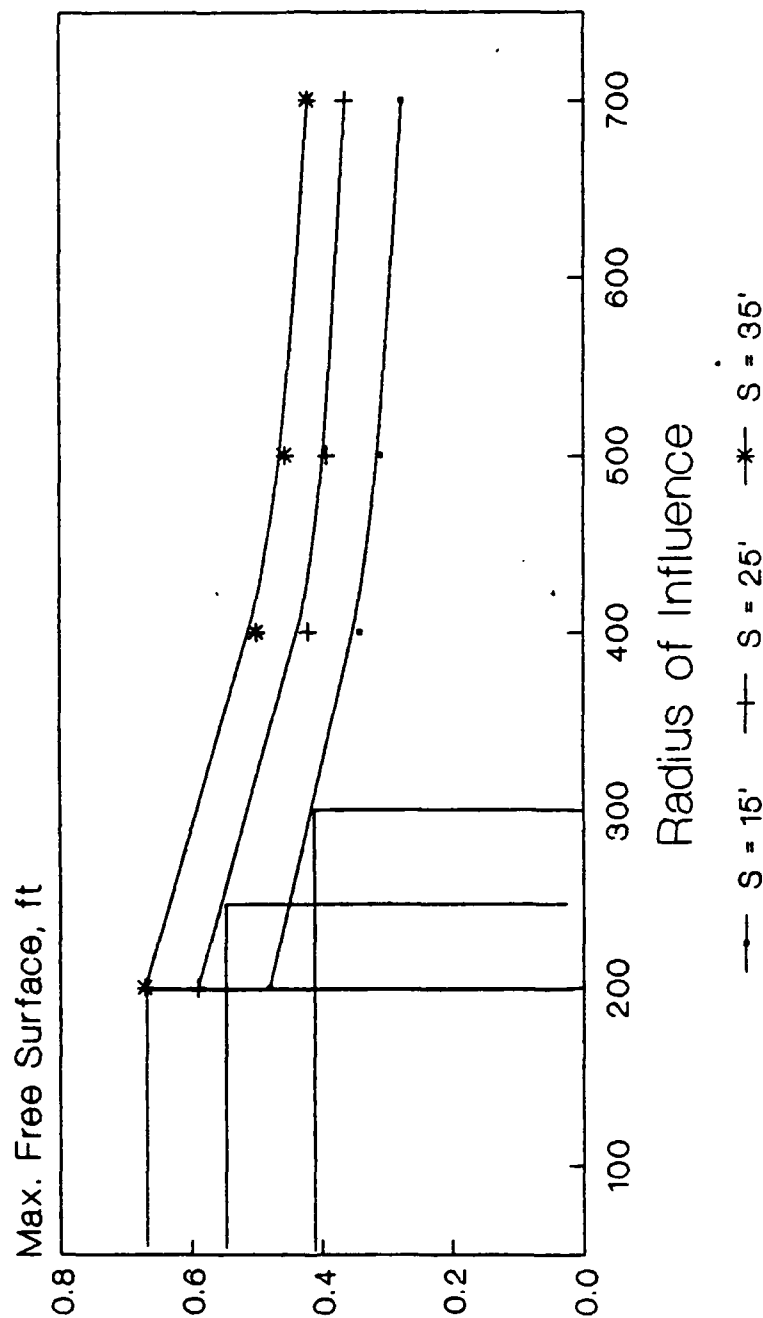


Fig. 3-14
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 3.5%, $H = 20'$, $h = 20'$)

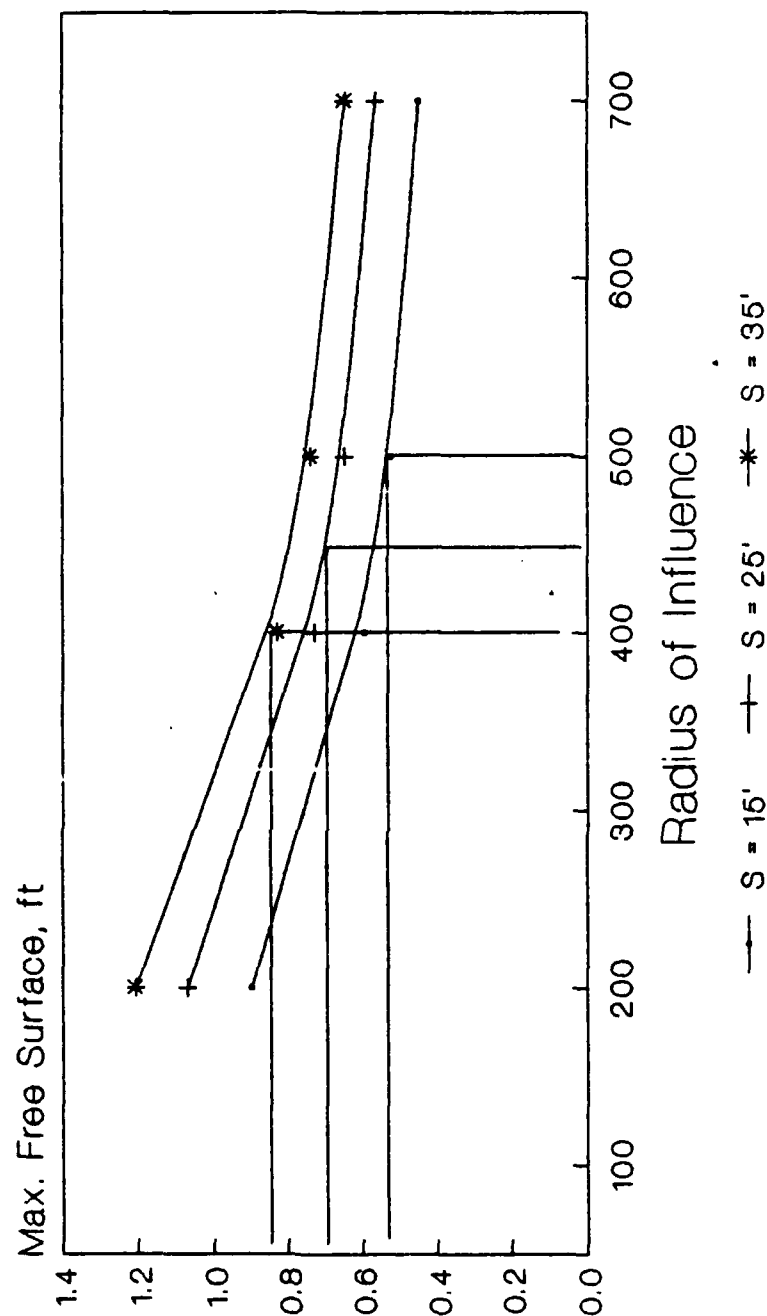


Fig. 3-15
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 3.5%, $H = 60'$, $h = 10'$)

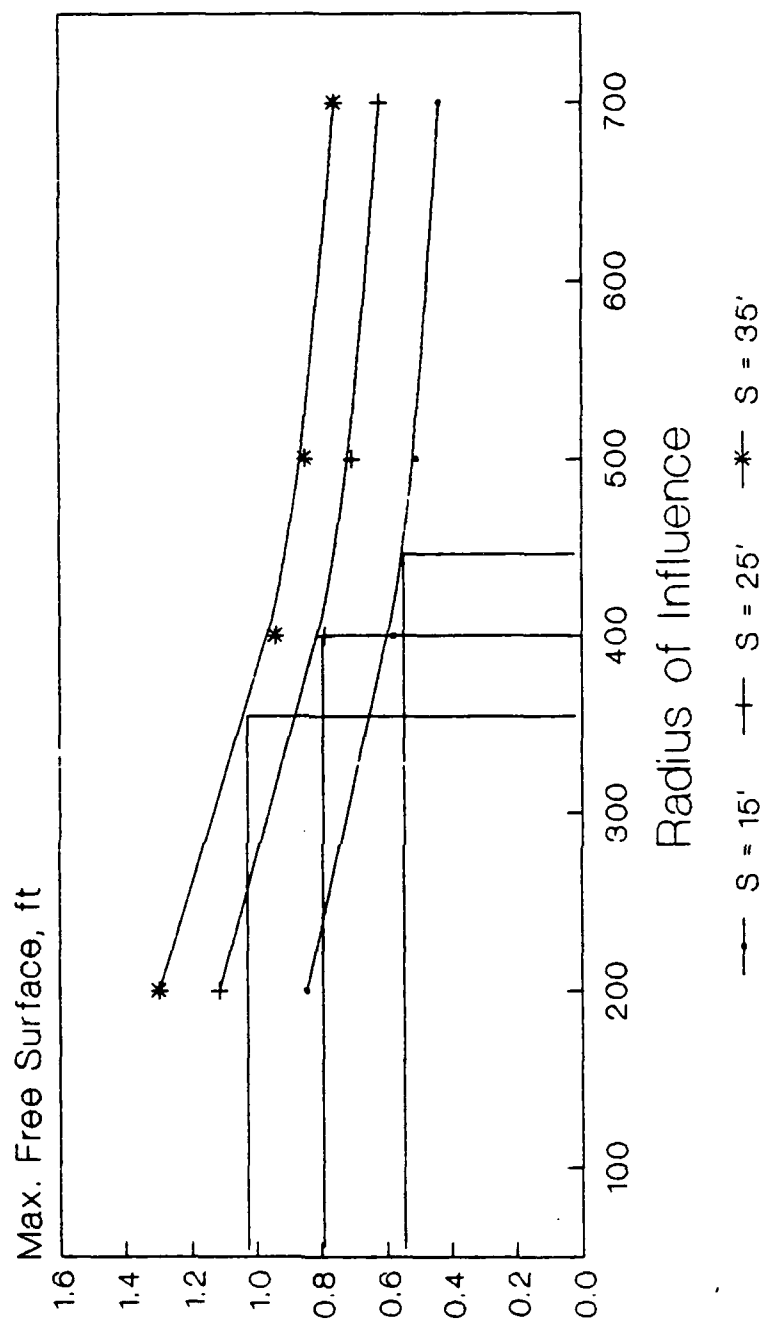


Fig. 3-16
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 3.5%, $H = 60'$, $h = 20'$)

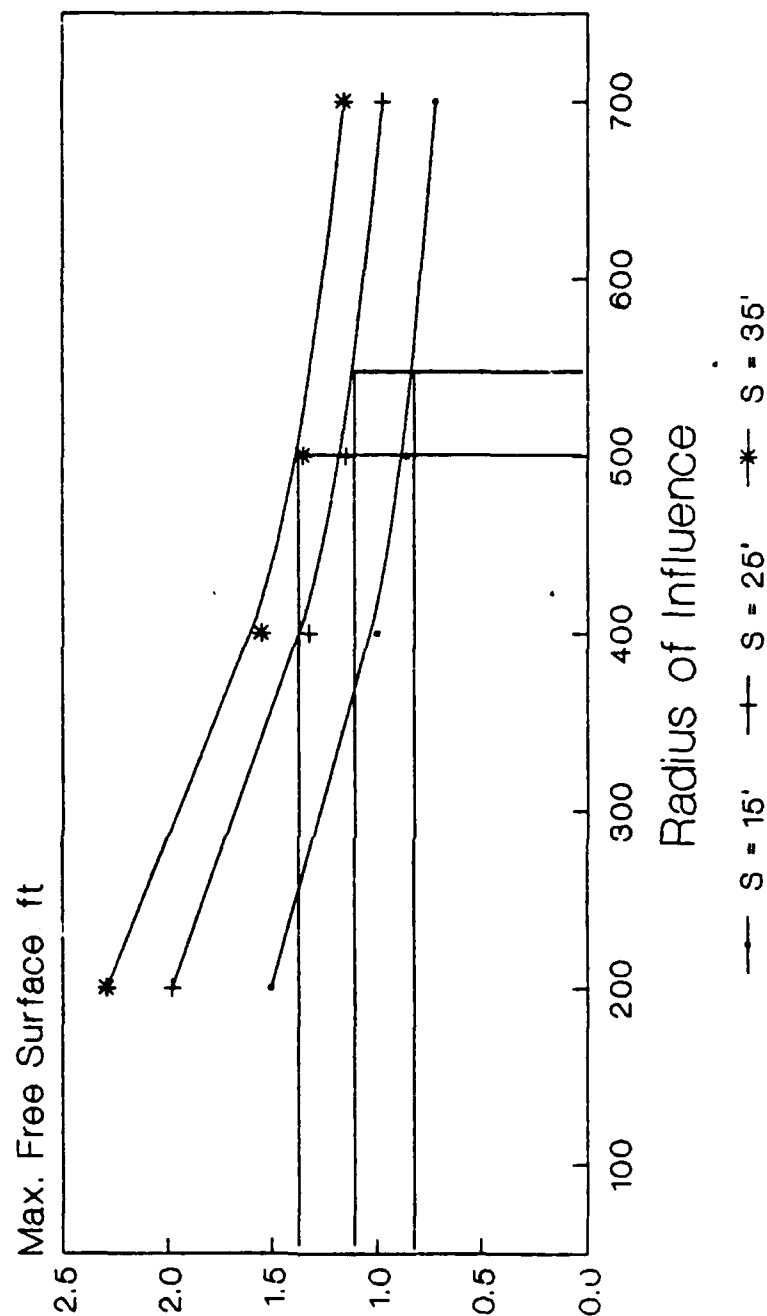


Fig. 3-17
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 7%, $H = 20'$, $h = 10'$)

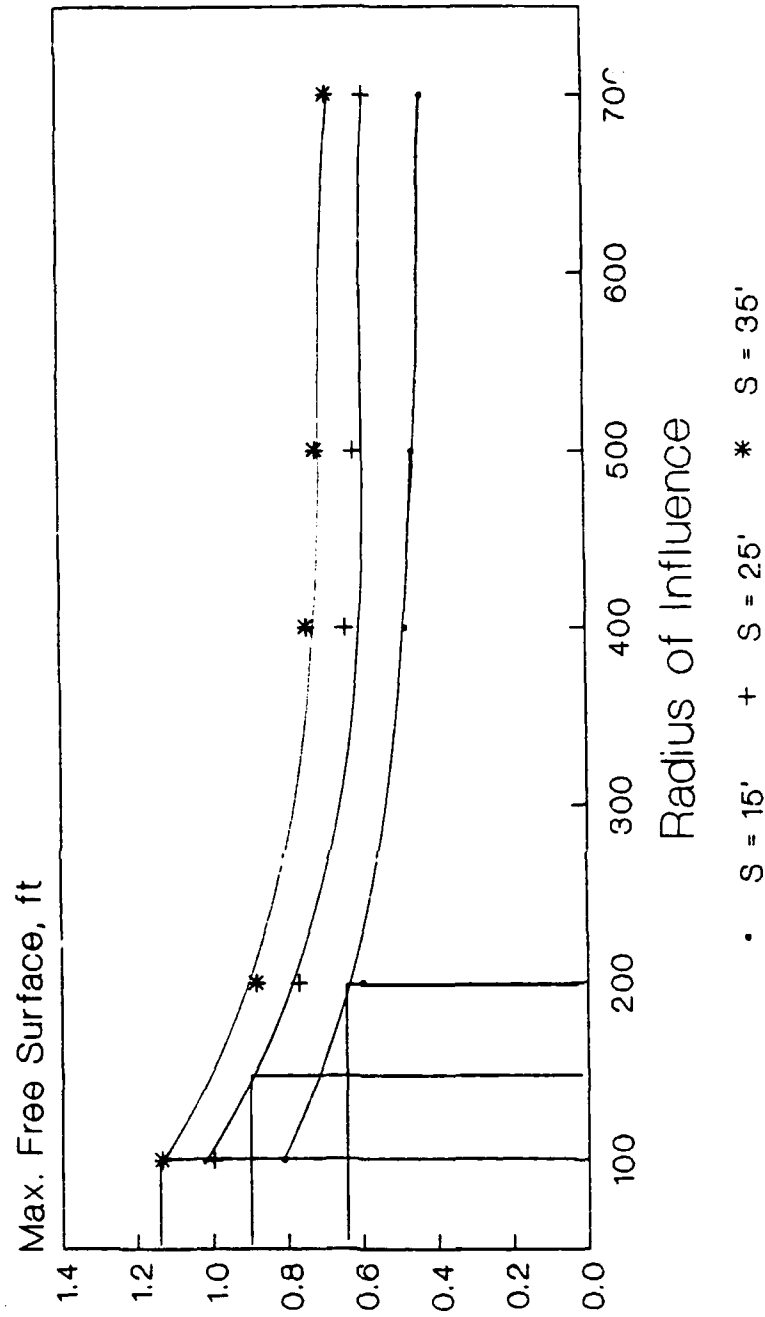


Fig. 3-18
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 7%, $H = 20'$, $h = 20'$)

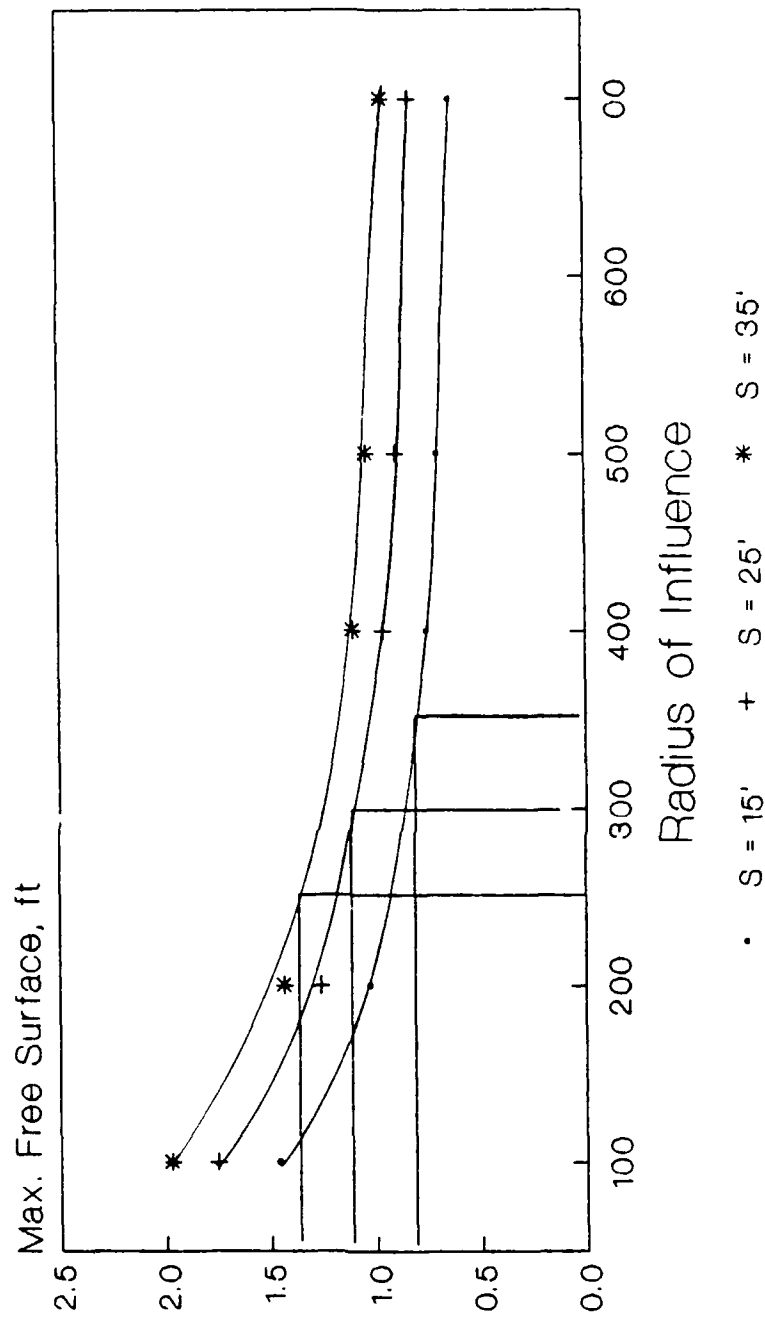


Fig. 3-19
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 7%, $H = 60'$, $h = 10'$)

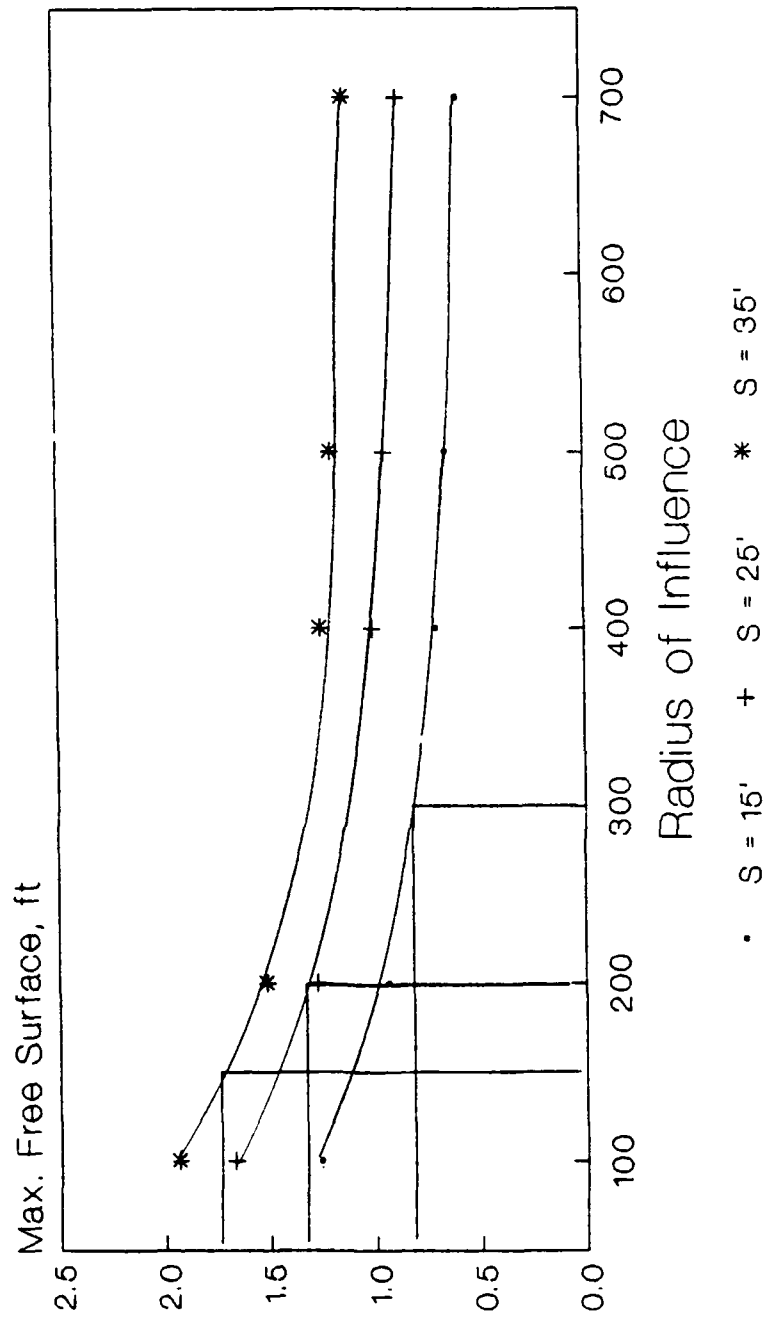


Fig. 3-20
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 7%, $H = 60'$, $h = 20'$)

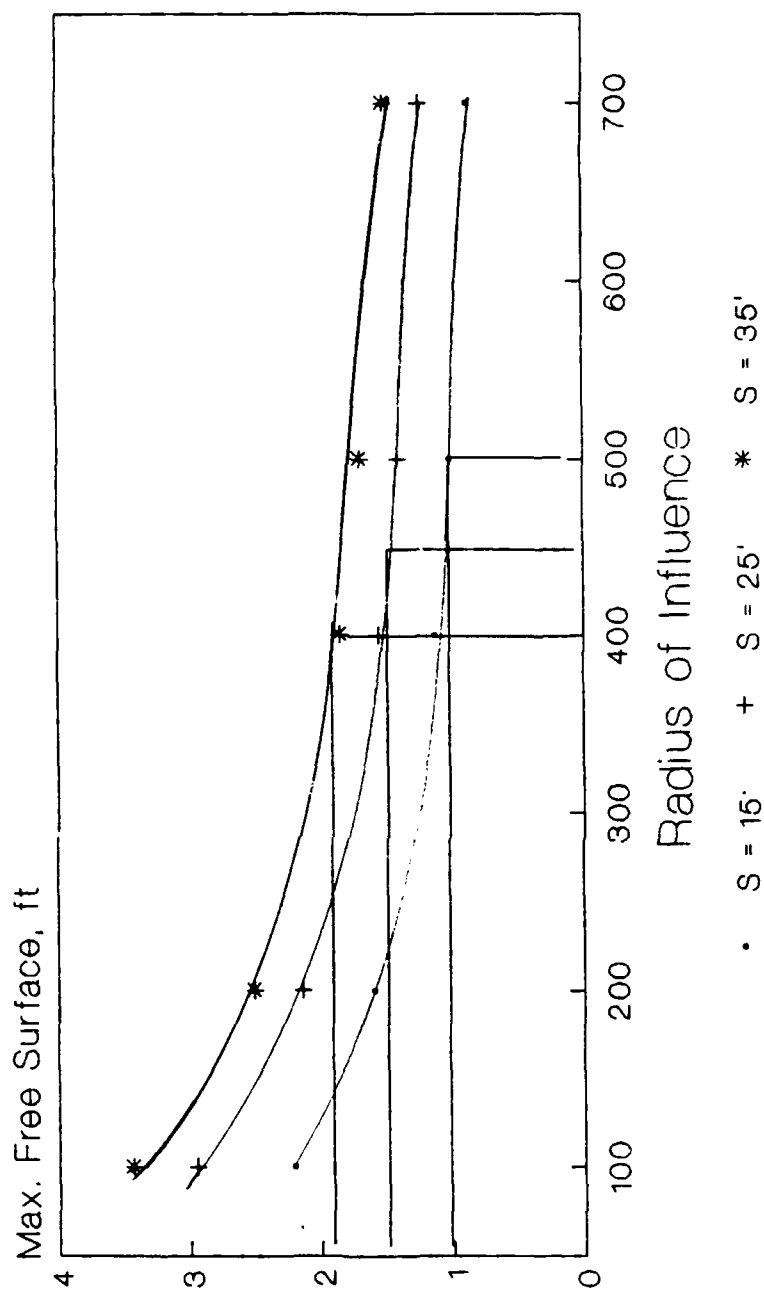


Fig. 3-21
Finding the Max. Free Surface
between trenches

V. Summary:

In summary there were three slopes considered, three spacings between drains, two elevations of trench and two free heads above the trench. That is thirty six geometries of problem, all considered under one horizontal and vertical hydraulic conductivity. While the physical dimensions of this problem are adequate to cover the majority of cases under which trench drains would be utilized, the single values of k leave room for further evaluation. With the use of dimensional analysis this study might serve to allow extrapolation of results for different hydraulic conductivities but, validation by further modeling is recommended.

CHAPTER 4

ANALYSIS OF TRENCH DRAIN DEWATERING

I. Introduction:

Modeling a foundation trench drain system with the a finite element analysis provides a myriad of results for many different conditions. For the analysis to be of use it must be presented so that future systems of trench drains can have capacities and limitations predicted from the results. This chapter is the presentation of results for use in prediction and selection of a trench drain system.

II. Results:

Chapter 3 details the input and output of this trench drain analysis. In Appendix A, Table A-1 summarizes the different variables and trench drain systems evaluated. From the data collected the total flow of a trench drain system with four drains in an isotropic soil can be determined for a range of design characteristics which are reasonable minimums and maximums. From this output information trends can be identified for the response to each variable.

The radius of influence was found from the measures described in Chapter 2. For each of the thirty six evaluated geometries of trench drain system four to six

computer models were run, each with a different trial radius of influence. Figures 2-1 through 2-12 show the results of these trials. As expected each trial of a lesser radius of influence predicted a greater total flow from the trench drain system. As the trial radius approaches the theoretically correct radius of influence the quantity of flow becomes unchanging and models the gravity flow condition accurately.

The spacing of trenches does not change the total flow of the trench drain system in a consistent pattern. The flow changed with other variables so that the single affects of spacing on flow is indistinguishable.

It is obvious that spacing directly influences the magnitude of the maximum free surface between trenches. On Table A-1 every combination of slope, trench elevation and free head has increasing maximum free surface with increasing spacing. This is consistent with expectations. Greater spacing decreases the influence of adjacent trenches. Figures 3-6 through 3-9 show that the maximum free surface in a sloping aquifer is strongly influenced by the upstream trench. The influence is even more strongly exhibited with increasing space. A larger spacing of trenches further isolates the upstream trench from drawdown influence from the inboard trenches.

In all cases the radius of influence decreased with increased aquifer slope. With greater slope, spacing of

the trenches exhibited the affect of decreasing the radius of influence. The dominant factor was the slope. The radius of influence was unchanging with spacing when the slope was zero.

Total flow did increase with the increasing slope of aquifer but, the magnitude of the change varied with the other variables so that a single affect from slope cannot be determined.

The maximum free surface increased consistently with the aquifer slope. The maximum free surface increased by 50%, for each 3.5% incremental change of slope, in every geometry considered.

Impact of different free heads above the trench was quite consistent and was normally coupled with the elevation of the trench. For constant elevation of trench the radius of influence increased with free head. In a similar manner the total flow increased with free head, with the magnitude of change impacted by the variables considered. The maximum free surface also showed a significant increase with free head when the elevation of the trench is constant.

For a constant free head with changing elevation of trench the same trends in radius of influence, total flow and maximum free surface can be seen. The magnitude of the change is not as great and the greater influence of free head can be inferred.

In this study only one drain width was considered and so the individual impact of a changing width cannot be determined. Only one vertical and horizontal hydraulic conductivity combination was studied and all studies were done on a four trench system so the affects of these single variables cannot be reported.

The many results of this study show the necessity for a form of dimensional analysis in evaluating a model affected by many variables. Some trends can be predicted from a couple of variables but, a complete prediction of performance or trend is not possible without a dimensional analysis.

III. Results of Predictive Formulas:

It is not surprising that no single numeric method exists for the evaluation of a trench drain system of four drains, in a sloping aquifer. This study attempts to provide that solution but, do other, existing solutions serve the need? In Chapter 2 several formulas were referenced in the discussion of determining a radius of influence. In this section several formulas are evaluated. The formulas below are presented with the variables used in this study rather than as presented in the source. A comparison of the results for the below methods with the results of the finite element analysis are in Table 4-1.

a.)
$$Q_p = (.73 + .27(h/(h+H)) Kx((h+H)^2 - h^2)/L$$

Q_p =total flow, h =free head, H =trench elevation, x =trench length, K = permeability, L = radius of influence (use consistent units)

The above formula (Leonards, pg 273) has the advantages of being for a partially penetrating slot in an unconfined aquifer. The disadvantages are that it has no provisions for a sloped aquifer, multiple trenches, trench width or means for calculating the maximum free surface. The radius of influence is a value of input to this formula.

b.) Figures 36, 61, 68 and 69 (Moulton)

The referenced charts offer allowances for sloping aquifer, two drains, partial penetration of the aquifer and a means of calculating a maximum free surface between drains. Some disadvantages of the methods are the lack of trench width, no allowance for more than two drains and a half space solution to the zero slope portion. The radius of influence is an input variable to solution. As listed in Chapter 3 the recommended radius of influence is $3.8 \cdot h$. This value yields a maximum radius of influence of 76 feet for this study. This value was much less than used throughout the study and yielded results far greater than predicted from the finite element analysis. In Table

4-1 the radius of influence used was that from the finite element analysis which yielded results much closer to those of the other calculations.

c.) $Q/x = K((H+h)^2 - h^2)/L$ ((a) Powers, pg 100)

Q= total flow, x= trench length, K= permeability, H= trench elevation, h= free head, L= radius of influence
(Use consistent units)

This method is a traditional trench solution. It does not make allowance for partial penetration of the aquifer, multiple trenches, trench width or aquifer slope.

d.) $G = S_y L q / K H^2$ and figures 18(b) and (c)

(Freeze, pg 261) G= dimensionless product, S_y = Specific Yield, L= radius of influence, q= total flow per unit width, K= permeability, H= aquifer thickness (use consistent units)

This solution is for a partially penetrating trench. Once again this method makes no provision for multiple trenches, trench width, sloping aquifer. In addition the Specific Yield is used adding another variable, this one normally varying between .01 and .3 (Freeze, pg 61).

Each of the above methods have several disadvantages and were not developed for use in the evaluation of a trench drain system. Assuming that the finite element analysis is the most accurate of the means of evaluation tried it is obvious in Table 4-1 that no single formula

TABLE 4-1 Summary of Predictive Methods
Summary

| | A | B | C | D |
|-----------------------------------|------|------|------|------|
| Slope | 0 | 3.5 | 3.5 | 7 |
| Spacing (ft) | 35 | 15 | 35 | 25 |
| Trench El (ft) | 60 | 20 | 60 | 20 |
| Free Head (ft) | 10 | 20 | 20 | 10 |
| (Mansur, pg 273) | | | | |
| total flow (ft ² /day) | 0.5 | 0.46 | 0.81 | 0.55 |
| (Moulton, pg 120 & 130) | | | | |
| total flow (ft ² /day) | 0.49 | 0.22 | 0.73 | 0.42 |
| (Powers, pg 100) | | | | |
| total flow (ft ² /day) | 0.66 | 0.53 | 1.02 | 0.66 |
| (Freeze, pg 261) | | | | |
| total flow (ft ² /day) | 5.88 | 0.64 | 5.12 | 2 |
| Anal Seepage Program | | | | |
| total flow (ft ² /day) | 0.14 | 0.19 | 0.25 | 0.27 |
| Radius of Infl u (ft) | 500 | 500 | 500 | 150 |
| Trial Radius 200' | | | | |
| Total Flow (ft ² /day) | .3 | .45 | .54 | .26 |

approximates the solution to the problem very closely. Of the evaluated methods the Moulton method, using the radius of influence as determined by the finite element analysis was the most accurate. It is worth noting that with no other means of selecting a radius of influence the value determined in this study was used for each method. This approximation would certainly affect the results. Appendix E is a discussion of the affect of arbitrary selection of radius on total flow and free surface height.

IV. Prediction of Trench Drain Performance:

The prediction of total flow and maximum free surface is possible through the use of results presented in a dimensionless form. As a trial some runs were done to explore the affects of anisotropy and number of trenches. These results are discussed below.

Any prediction of flow characteristics requires an evaluation of the radius of influence. Figures 4-1 through 4-3 are useful for predicting the radius of influence from the trench elevation, free head, slope of aquifer and the trench spacing. These figures are only appropriate for an isotropic condition in a four trench system with a trench width of 1.5'. Use of the figures will frequently require several interpolations.

Radius of Influence

(Four trench drains, Slope 0 to 7%
 $K_v = K_h$, trench width 1.5')

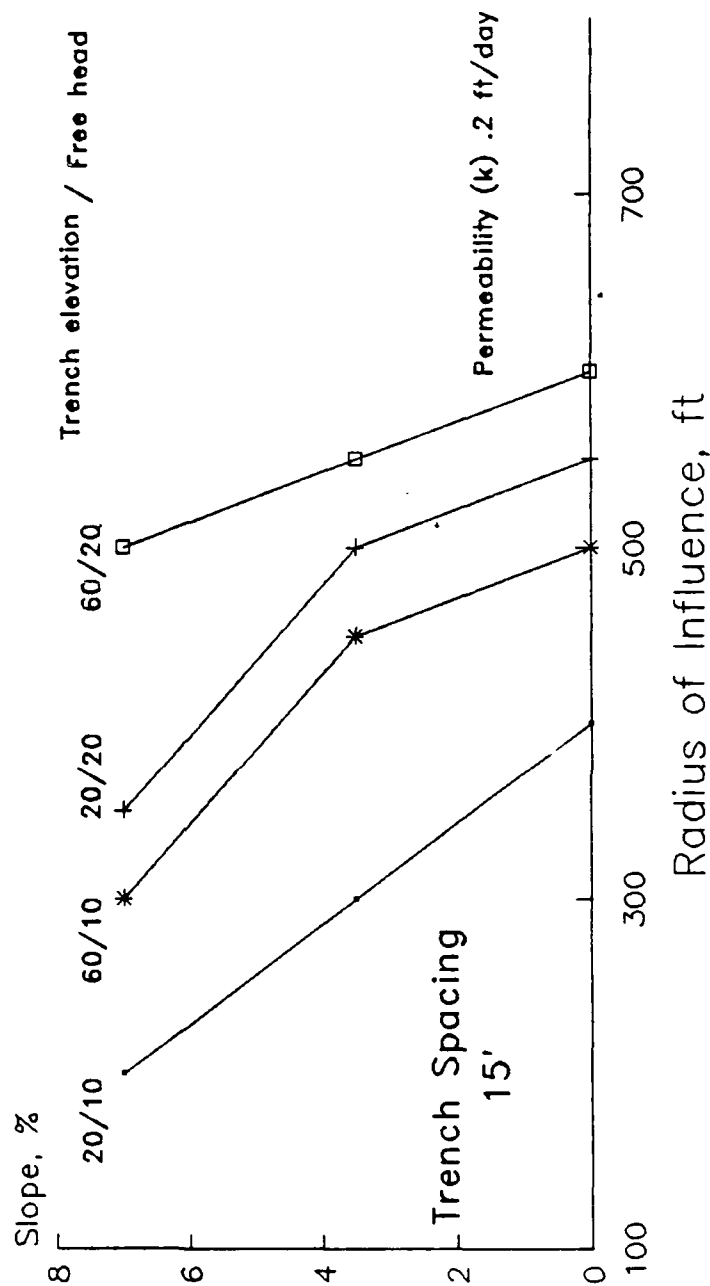


Fig. 4-1
Predicting the radius of influence

Radius of Influence

(Four trench drains, Slope 0 to 7%
 $K_v = Kh$, trench width 1.5')

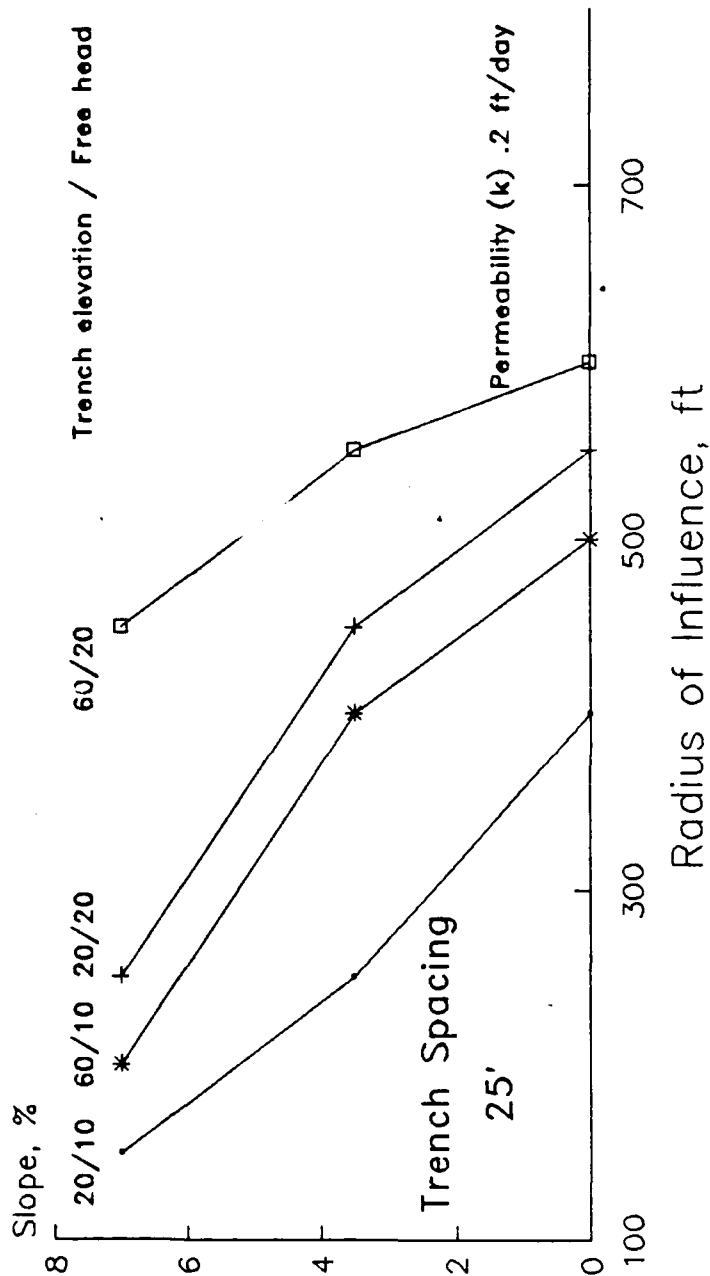


Fig. 4-2
 Finding the radius of influence

Radius of Influence

(Four trench drains, Slope 0 to 7%
 $K_v = K_h$, trench width 1.5')

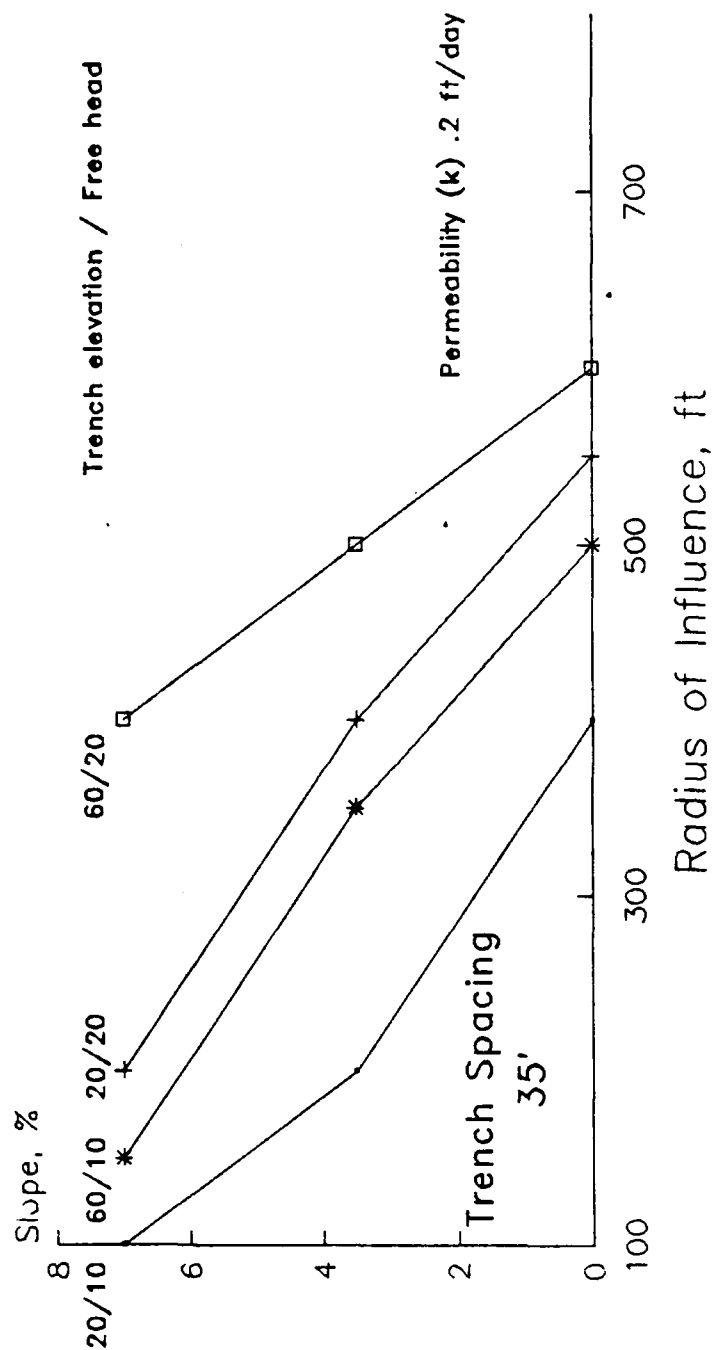


Fig. 4-3
 Finding the radius of influence

To use figures 4-1 through 4-3 the following example will be useful.

Example 4-1: Find the radius of influence for a four trench system with trench width of 1.5' and $K_v/K_h = 1$ with $K = .2$ ft/day. The trench elevation is 40 feet, the free head is 15 feet, the trench spacing is 30 feet and the aquifer slope is 4%.

a. Figure 4-4 is annotated from Figure 4-2. Follow this figure through the following steps.

b. At slope = 4% on Figure 4-2 interpolate between the lines labeled 20/10 and 20/20 as well as between 60/10 and 60/20. These are the points for trench elevations of 20 and 60 feet with a free head of 15 feet. The radii of influence for these two points are 330 feet and 456 feet.

c. Again at slope = 4% interpolate between the above two points to find the radius of influence for a trench elevation of 40 feet and a free head of 15 feet with a spacing of 25 feet. This radius of influence is 394 feet.

Radius of Influence

(Four trench drains, Slope 0 to 7%
 $K_v = K_h$, trench width 1.5')

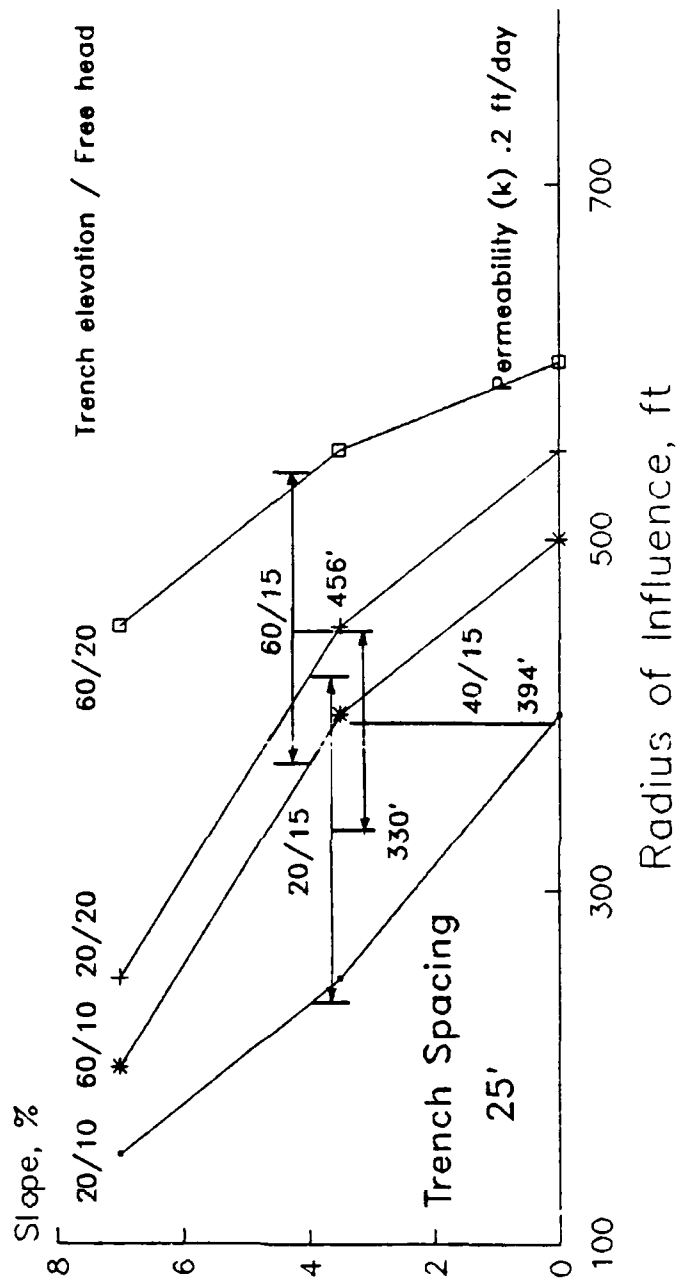


Fig. 4-4
 Finding the radius of influence
 for example 4-1

d. Follow the above procedure again on Figure 4-3 to get a radius of influence of 344 feet when spacing is 35 feet.

e. For a spacing of 30 feet interpolate between the results of steps c. and d. above to get a final predicted radius of 369 feet.

As an alternate method a rough selection of 350 or 400 feet will not make a significant difference in the following calculation method. As discussed in Chapter 2 the radius of influence is an extremely variable value, often approximated only within an order of magnitude. One suggested method (Moulton, pg 66) has the radius of influence estimated as 3.8 times the free head. In this example that would predict a radius of only 53 feet, one seventh of that from this study but, within one order of magnitude.

In Chapter 2 the derivation of the dimensionless product used in this study was reviewed. The product which best presented the behavior of total flow and maximum free surface with the changing variables of the problem geometry was:

$$Ld/h(h+H) \quad (2)$$

Where L = radius of influence, d = trench width, h = free head and H = trench elevation as shown on Figure 3-4. Using consistent units for the variables yields a dimensionless product.

Figures 4-5 and 4-6 are total flow and maximum free surface, respectively against the dimensionless product for the considered geometries. In both plots an acceptable curve fit is possible. The points are aligned with the largest aquifer slope to the left and the zero sloped aquifer to the right. This observation is for interest only as the dimensionless product provides sufficient accuracy with the sloping aquifer influence represented by the values of total flow, maximum free surface and radius of influence. From the previous example:

- a. Calculate $Ld/h(h+H)$. For this problem using the above $L = 369$ feet,

$$Ld/h(h+H) = 369' * 1.5' / 15' (15' + 40') = .671$$
- b. From Figure 4-5 total flow $q = .25 \text{ ft}^2/\text{day}$
- c. From Figure 4-6 maximum free surface
 $F = .9 \text{ ft}$

As a check of the accuracy of this method to predict the output of the finite element analysis six sample runs were conducted. The values of the variables and the results of the finite element analysis are shown in Table

TOTAL FLOW

(Four trench drains, 0 to 7% slope,
 $K_v = Kh$, trench width 1.5')

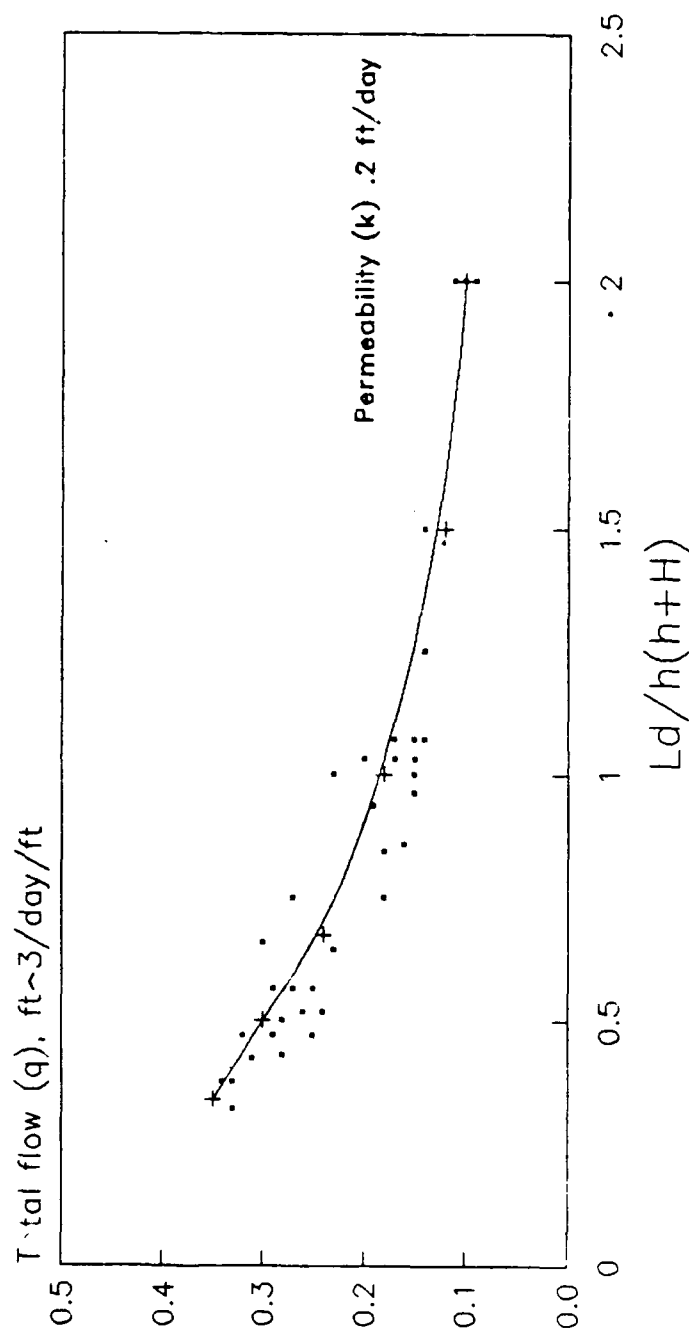


Fig. 4-5
 Predicting flow from a
 dimensionless product

MAXIMUM FREE SURFACE (Four trench drains, Slope 0 to .7% $K_v = Kh$, trench width 1.5')

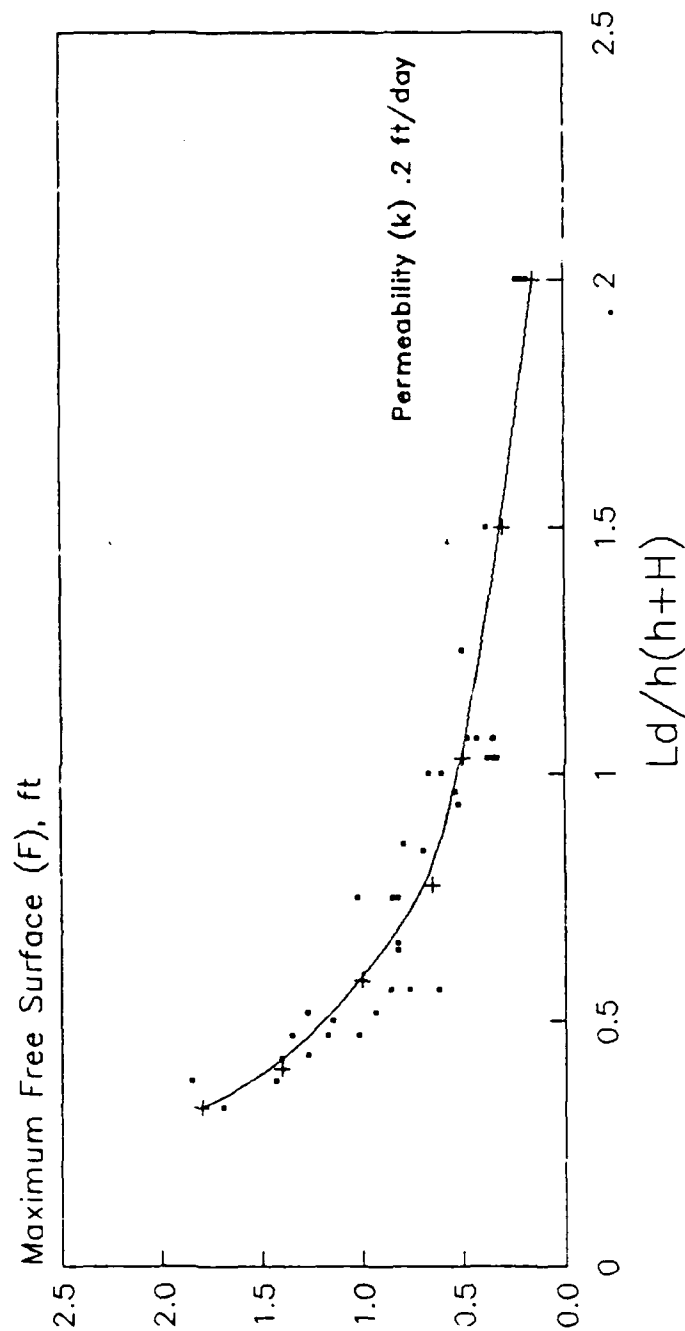


Fig. 4-6
Finding the maximum free surface
from a dimensionless product

A-2. For this analysis three trial radii of influence were used for each sample run. The theoretically correct radius of influence, total flow and maximum free surface were taken from plots similar to Figures 2-1 and 3-10.

The determination of the theoretically correct radius of influence is done under an arbitrary standard to an accuracy of fifty feet. From Table A-2 the prediction of total flow and maximum free surface agree with the results of the finite element sample runs. This is excellent accuracy in selecting the radius of influence. This method is acceptable for an isotropic soil with a four trench system.

Figures 4-5 and 4-6 were prepared assuming an isotropic condition. As a matter of interest several finite element runs were done modeling a four drain system with various conditions of anisotropy. Normally soils are anisotropic with K_v/K_h between .1 and .33. The results of these sample runs are shown on Figures 4-7 and 4-8, where the affects of differing hydraulic conductivity and anisotrophic soil are explored.

From Figure 4-7 it appears that different lines, nearly parallel, exist for a four drain systems with the line of largest total flow having the highest hydraulic conductivity and the line of lowest flow with the lowest hydraulic conductivity. The lines of differing conductivity may converge to the left side of the plot.

TOTAL FLOW

(Four trench drains, 0 to 7% slope,
 $K_v \neq Kh$, trench width 1.5')

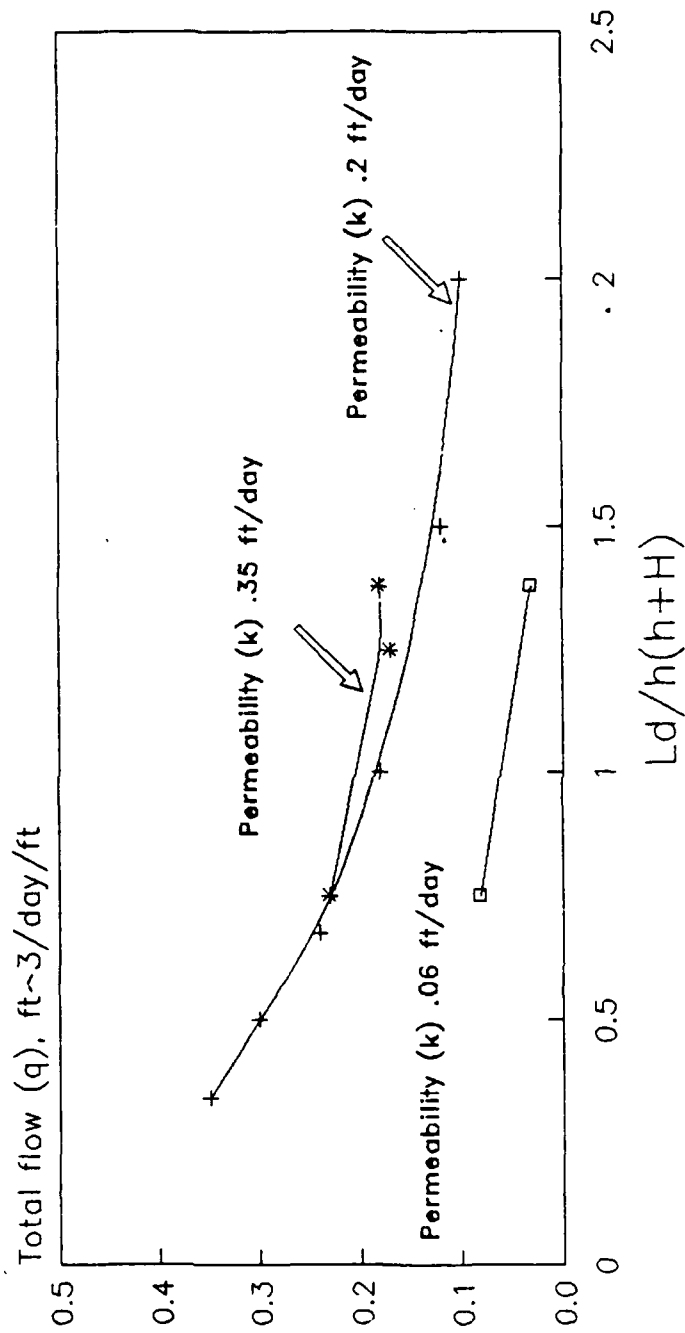


Fig. 4-7
 Permeability and Flow with a
 dimensionless product

MAXIMUM FREE SURFACE (Four trench drains, Slope 0 to 7% $K_v \neq K_h$, trench width 1.5')

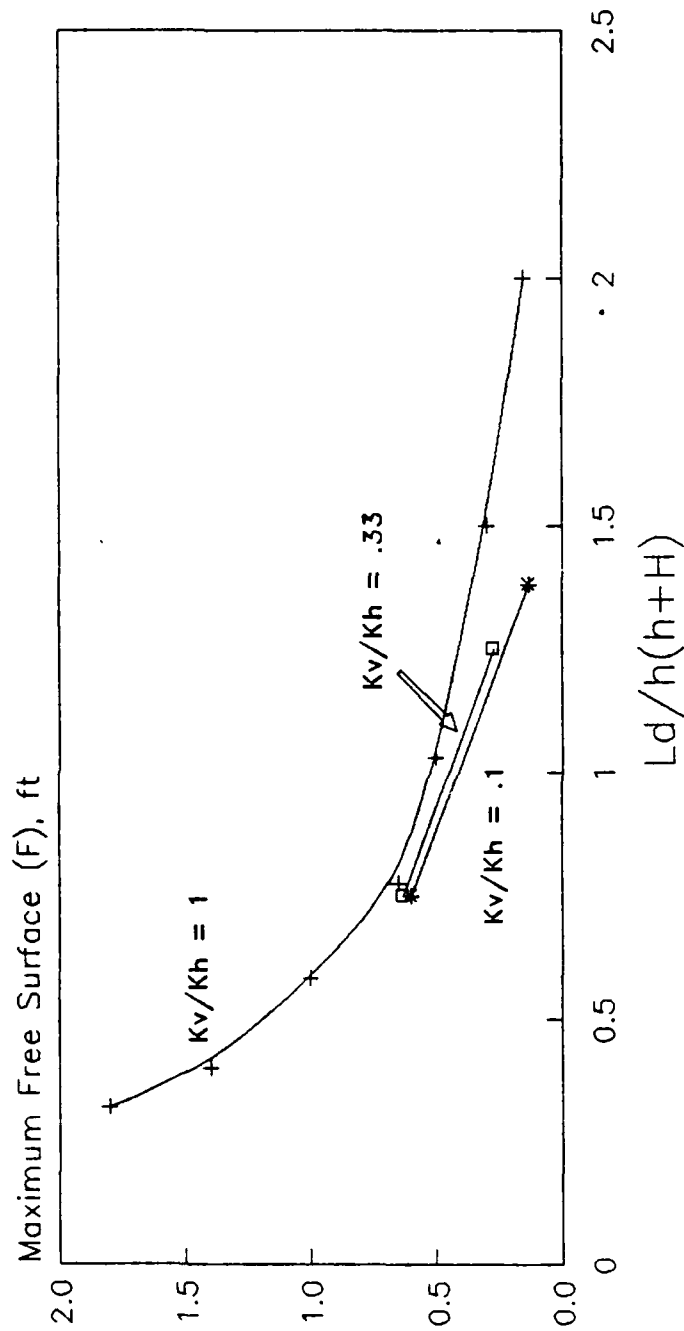


Fig. 4-8
 Anisotropy and maximum free surface
 from a dimensionless product

The degree of anisotropy appears to have no consistent pattern.

Figure 4-8 shows the opposite influence. The degree of anisotropy, represented by K_v/K_h , would have parallel lines with decreasing maximum free surface as the degree of anisotropy decreases. The lines of this plot may also converge to the left as $L_d/h(h+H)$ decreases.

Another area of interest is the affect of a differing number of trench drains. As a means of predicting the ultimate affect of systems with more or less drains then the four evaluated. Figures 4-9 and 4-10 show the results of three runs of a three trench system. While not conclusive it is likely that the line for a three trench system is just below the four trench line. With further study it might be possible to extend the results of a four drain analysis based on the paralleling trends of lines for the different trench configurations.

TOTAL FLOW

(3 & 4 trench drains, 0 to 7% slope
 $K_v = Kh$, trench width 1.5')

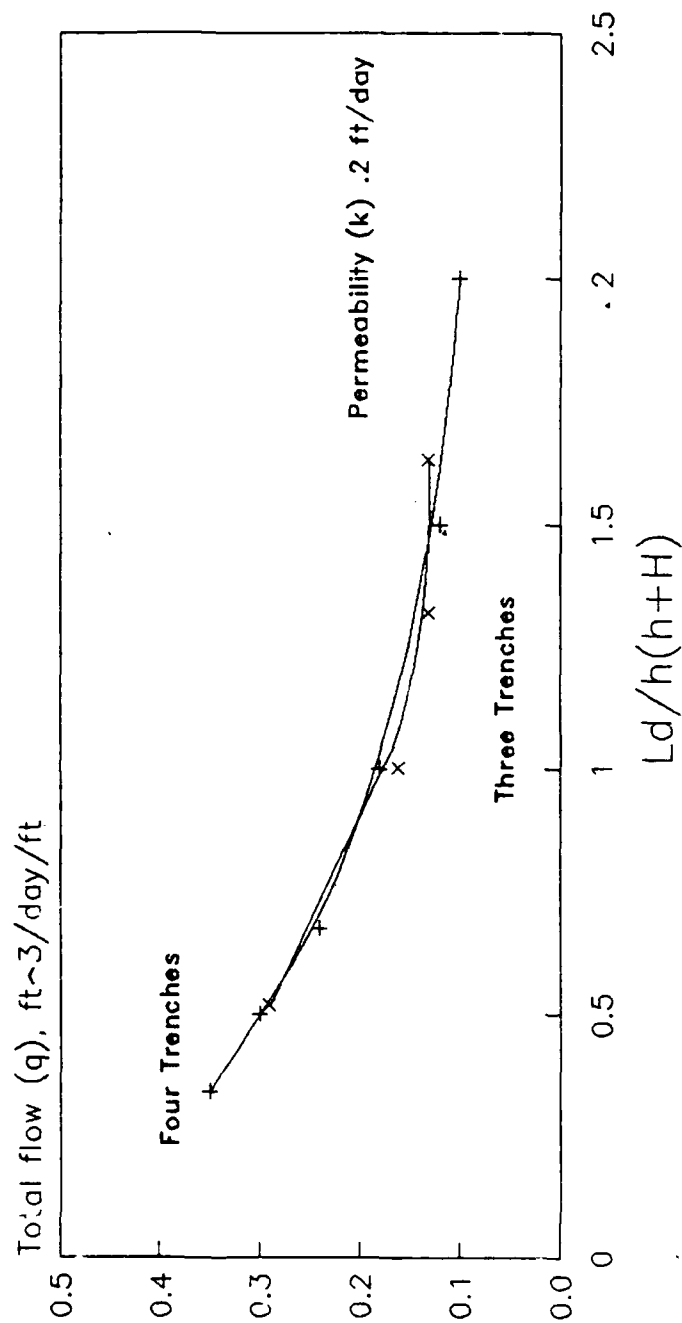


Fig. 4-9
 Comparison of Three Drain System
 in dimensionless product

MAXIMUM FREE SURFACE (3 & 4 trench drains, Slope 0 to 7% $K_v = Kh$, trench width 1.5')

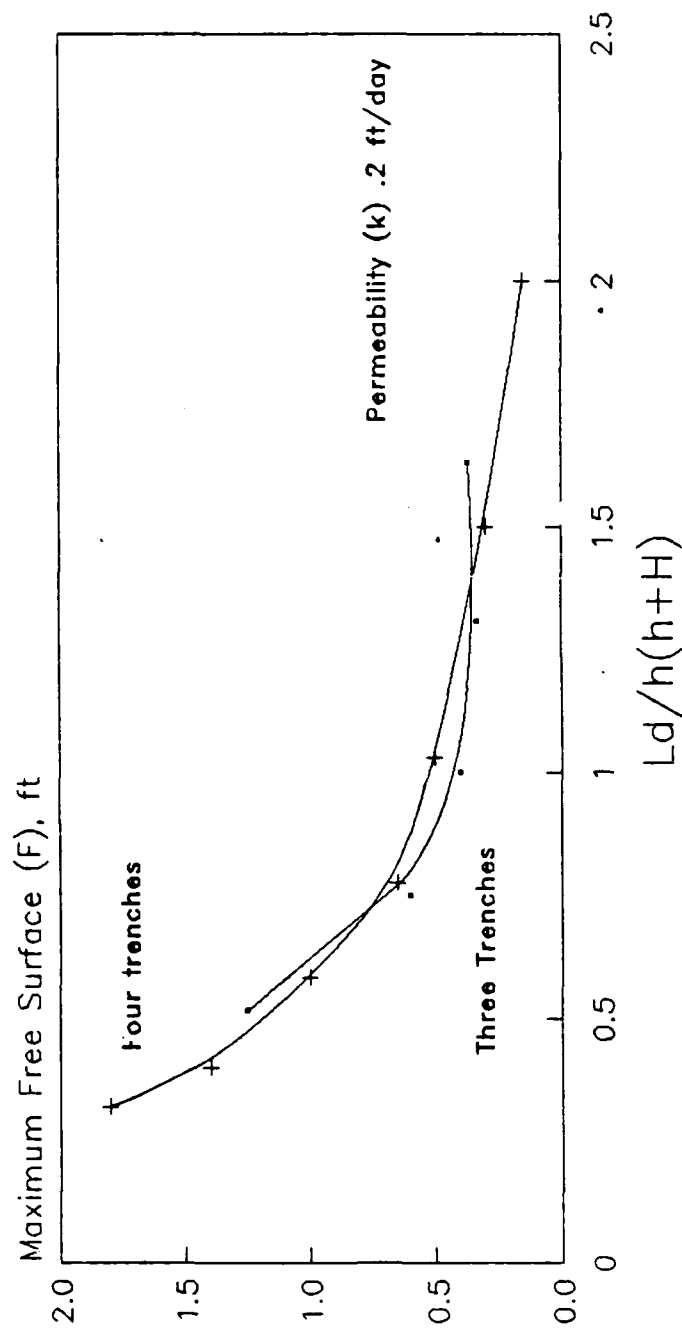


Fig. 4-10
3 & 4 Trenches for maximum free surface
from a dimensionless product

This study has developed an effective method for determining the total flow and maximum free height for a trench drain system, knowing the geometry of the problem. It appears probable that anisotropic conditions, different hydraulic conductivities and trench systems with other than four drains can be included into this type of evaluation with some further research.

V. Comparison of Trench Drain with Blanket Drain:

An alternative to the trench drain system for dewatering beneath a foundation is the blanket drain. A blanket drain system is similar to the trench drain system as it is a mass of open graded stone or gravel isolated from the soil by a geosynthetic filter material and has slotted collector pipes to carry water to a sump for removal. It is different in geometry. The blanket drain is a single rectangular cross section which dewateres the surrounding soil to the depth of the bottom of the section. The trench drain uses less gravel by extending the dewatering depth down with narrow trenches extending from a thin base of gravel across the bottom of the foundation (Figure 3-4).

The blanket drain does an excellent job of dewatering beneath a foundation and has the advantage of easier construction. The biggest difference between the two systems in a practical application is the cost. The trench system requires more detailed labor and excavation

while the blanket drain requires more gravel. To do a cost comparison of the two methods a standard foundation size was necessary to determine the excavation, placement and compaction productivity rates. In this study a foundation of 100 feet by 200 feet was used, only for the establishment of unit costs of labor.

The evaluation is done based on a set slab elevation and a predetermined base of trench or blanket drain. That is the blanket drain will have to be thick enough to dewater to the depth of the trench drain without lowering the foundation. A basic cost to this evaluation was the cost of gravel (#57 stone) which goes for \$8.30/ton in the Atlanta area. Labor costs used were \$20/hr for an equipment operator and \$16/hr for a laborer (both rates including overhead and fringes). Productivity values came from the Means estimating guide for 1989. The cost of equipment rentals were approximated from the same guide. The cost of the geosynthetic filter material was estimated as \$0.70/yd² from discussions with suppliers and engineers in the Atlanta area.

The cost data was input into a spreadsheet with a variety of possible trench drain configurations. The costs were calculated for both the trench drain and an equivalent blanket drain for several different systems each with more drains. Table 4-2 is a copy of one such trial. With the cost of gravel so much higher then the

filter material the ratio of trench drain cost to blanket drain cost was less than one in all cases.

With a blanket drain at a shallow elevation the cost comparison is more likely to recommend a blanket drain system. Figure 4-11 is a summary of such a comparison. To use a thickened blanket drain will sacrifice drawdown capacity in exchange for some construction ease and cost benefits. The decision will depend on the application.

TABLE 4-2

Trench and Blanket Drain Costs

| Excavation unit costs | | | Material costs (in place) | | |
|-----------------------|--------------|--------------|---------------------------|-----------------|------------------|
| Trench | 0.4 | \$/cu.ft | Geosyn | 0.08 | \$/sq.ft |
| Blanket | 0.08 | \$/cu.ft | Gravel Tr | 0.45 | \$/cu.ft |
| | | | Gravel Bl | 0.9 | \$/cu.ft |
| | | | per unit lngth | | |
| Spacing | Trench Width | Trench Depth | Number of Trenches | Trench Total \$ | Blanket Total \$ |
| 15 | 1.5 | 1 | 30 | 38.25 | 508.96 |
| 15 | 1.5 | 4 | 30 | 153 | 1920.64 |
| 15 | 2.5 | 1 | 30 | 63.75 | 540.76 |
| 15 | 2.5 | 4 | 30 | 255 | 2040.64 |
| 25 | 1.5 | 1 | 30 | 38.25 | 816.36 |
| 25 | 1.5 | 4 | 30 | 153 | 3080.64 |
| 25 | 2.5 | 1 | 30 | 63.75 | 848.16 |
| 25 | 2.5 | 4 | 30 | 255 | 3200.64 |
| 35 | 1.5 | 1 | 30 | 38.25 | 1123.76 |
| 35 | 1.5 | 4 | 30 | 153 | 4240.64 |
| 35 | 2.5 | 1 | 30 | 63.75 | 1155.56 |
| 35 | 2.5 | 4 | 30 | 255 | 4360.64 |

Cost, Trench vs Blanket (Same size foundations, dewatering to different depths)

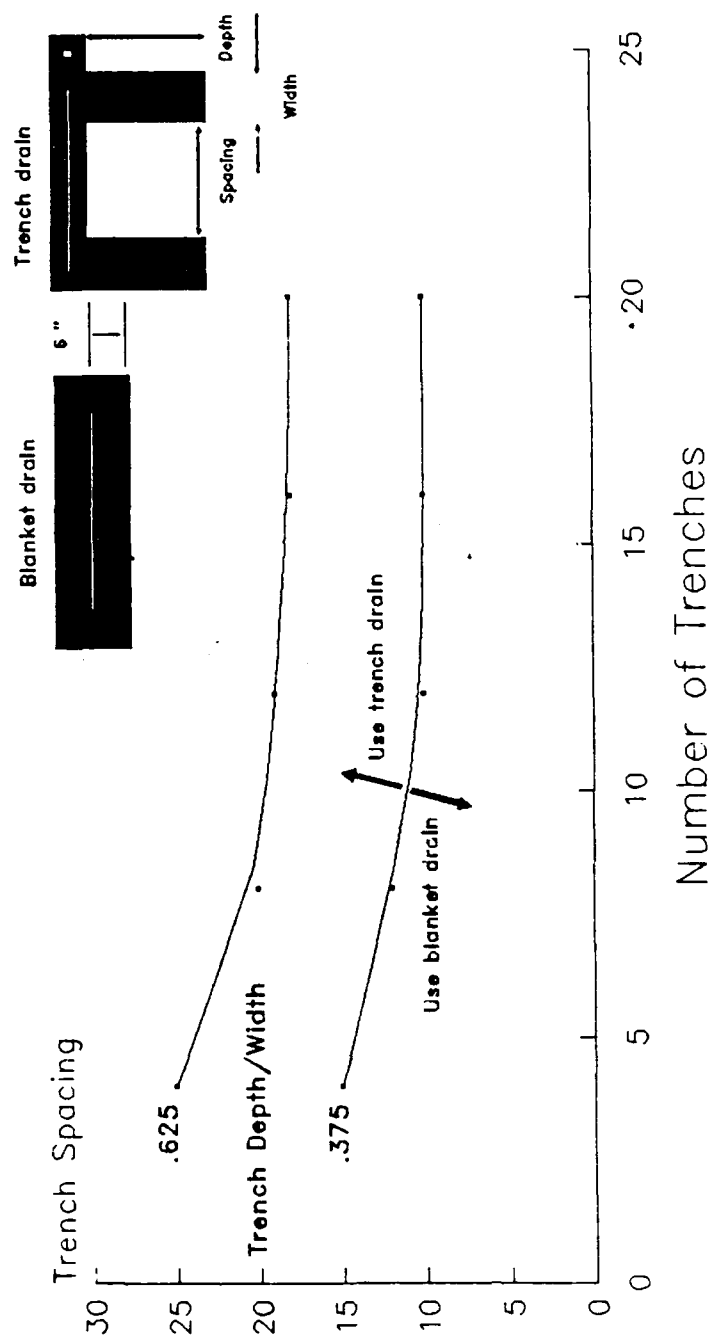


Fig. 4-11
Spacing for economic use of Trench
Drain, dewatering to greater depth

VI. Conclusions:

In this chapter a method for predicting the results of a finite element analysis of a trench drain system for isotropic soil and four drains is presented. A rough approximation has been made to show the possible impact of anisotropy and different trench configurations. Empirical data is not available to validate or modify the predictions of the Aral Seepage Program for a trench drain system. Compared with other slot drain solutions it appears that the finite element solution predicts lesser flows and is so less conservative.

The use of a trench drain system can be justified economically over a blanket drain system in some configurations. The brief evaluation of this chapter provides a simple comparison method for the relative cost differences of the two systems.

CHAPTER 5

CONCLUSIONS

I. Introduction:

In this study the trench drain system was evaluated for thirty six configurations using a finite element analysis program. The results of the analysis were used under dimensional analysis to form a method of predicting the results of a similar analysis for any configuration of a trench drain system within the limits of the study. The final portion of the study was to evaluate the cost of a trench drain system as compared with the blanket drain system for use in a drain beneath a foundation.

II. Trench Drain System Analysis:

The results of the finite element analysis could not be validated by test or field data nor, did the formulas available show close agreement with the results of the analysis. It would be useful if the actual outflow of a trench drain system were measured and the radius of influence of drawdown determined.

This study was limited to isotropic conditions and a four drain system. The affect of other conditions was briefly explored but, a more complete study is necessary before the results are extrapolated to conditions of many drains or variable soils. Initial expectations are that results of Figures 4-7 through 4-10 will be consistent with results of a more complete run of

variables. Whether more than four drains have significantly different shape than the four and three drain curves will be most important when the cost comparison of trench and blanket drains is considered from Figure 4-11.

The one recurring constant in the reference material on dewatering is the variable nature of the radius of influence. For the narrow conditions evaluated in this study reasonable estimations of the radius of influence are possible from Figures 4-1 through 4-3. The earlier recommendations of field observations and computer modeling with other ranges of variables would expand the information available for predicting the radius of influence.

The permeability used in this study, 0.2 ft/day is consistent with the soil in the Atlanta area. If the trench drain system is to be used in a greatly more permeable soil the results may be significantly different. It would not be recommended to use a trench drain in a very porous sand or gravel just as an open sump is not satisfactory to dewater a site of that composition. Establishing the upper and lower bounds of permeability for practical use of trench drains is a most useful recommendation for further study.

III. Predictive Method:

The predictive method using Figures 4-1 through 4-6 work well in predicting the results of the finite element analysis. The forms are easy to use and adapt readily to drain configurations within the range evaluated. The range of variables were selected

to match the conditions under which a trench drain system is normally used. Extrapolation of the results beyond these values may be of limited practicality and questionable accuracy.

The prediction of the maximum free surface at a low dimensionless product ($Ld/h(h+H)$) should be treated with great care. When the product is less than 0.5 the curve rises rapidly and the maximum free surface exceeds 1.25 feet only in this range. The maximum free surface is of concern only when the water level approaches the shallow blanket immediately beneath the slab, approximately one foot for most trench systems. The curve for the maximum free surface was roughly aligned with the 7% slope values at the left end and the 0% slope values on the right. For large aquifer slopes the curve may approach vertical and might be sufficient reason to avoid the use of a trench drain system in such an aquifer.

IV. Cost Comparison:

If the necessary depth of dewatering is to the depth of the trench drain system a blanket drain cannot compete on an economic basis. If a very shallow level of dewatering is required beneath the foundation it would not be practical to install a trench drain system. Trenches of under one foot depth would require individual consideration. By the results of Figure 4-11 it is apparent that even sacrificing the depth of dewatering is not sufficient to turn the advantage to blanket drains in all cases.

V. Evaluation:

The results of this study have satisfied the stated intentions. Results and input were reviewed with care and show consistent and reasonable trends. Appendix C is a brief description of the method of compilation of data, preparation of data files and execution of program commands. Also included in Appendix D is a storage disk for an IBM compatible computer with the spreadsheets of results and the data files used.

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APPENDIX A
SUMMARY OF PROGRAM COMPUTER RUNS

APPENDIX A

FINITE ELEMENT COMPUTER RUN SUMMARY

| | Trench Spacing | Elevation | Free Head | Radius of Influence | Total Flow | Max Free Surface | Number of Trials |
|--------------|-------------------|-----------|--------------|------------------------|---------------|---------------------|---------------------|
| Slope = 0% | | | | | | | |
| | 15 | 20 | 10 | 400 | 0.11 | 0.18 | 6 |
| | 15 | 20 | 20 | 550 | 0.2 | 0.33 | 6 |
| | 15 | 40 | 10 | 500 | 0.17 | 0.35 | 6 |
| | 15 | 40 | 20 | 600 | 0.29 | 0.615 | 6 |
| | 25 | 20 | 10 | 400 | 0.1 | 0.204 | 5 |
| | 25 | 20 | 20 | 550 | 0.17 | 0.35 | 5 |
| | 25 | 40 | 10 | 500 | 0.15 | 0.429 | 5 |
| | 25 | 40 | 20 | 600 | 0.27 | 0.763 | 5 |
| | 35 | 20 | 10 | 400 | 0.09 | 0.227 | 5 |
| | 35 | 20 | 20 | 550 | 0.15 | 0.38 | 5 |
| | 35 | 40 | 10 | 500 | 0.14 | 0.475 | 5 |
| | 35 | 40 | 20 | 600 | 0.25 | 0.853 | 5 |
| Slope = 3.5% | | | | | | | |
| | 15 | 20 | 10 | 300 | 0.14 | 0.38 | 4 |
| | 15 | 20 | 20 | 500 | 0.19 | 0.52 | 4 |
| | 15 | 40 | 10 | 450 | 0.15 | 0.53 | 4 |
| | 15 | 40 | 20 | 550 | 0.26 | 0.93 | 4 |
| | 25 | 20 | 10 | 250 | 0.14 | 0.5 | 4 |
| | 25 | 20 | 20 | 450 | 0.18 | 0.69 | 4 |
| | 25 | 40 | 10 | 400 | 0.16 | 0.79 | 4 |
| | 25 | 40 | 20 | 550 | 0.24 | 1.27 | 4 |
| | 35 | 20 | 10 | 200 | 0.15 | 0.66 | 4 |
| | 35 | 20 | 20 | 400 | 0.18 | 0.82 | 4 |
| | 35 | 40 | 10 | 350 | 0.18 | 1.02 | 4 |
| | 35 | 40 | 20 | 500 | 0.25 | 1.35 | 4 |
| Slope = 7% | | | | | | | |
| | 15 | 20 | 10 | 200 | 0.23 | 0.6 | 5 |
| | 15 | 20 | 20 | 350 | 0.3 | 0.82 | 5 |
| | 15 | 40 | 10 | 300 | 0.23 | 0.819 | 5 |
| | 15 | 40 | 20 | 500 | 0.29 | 1.014 | 5 |
| | 25 | 20 | 10 | 150 | 0.27 | 0.85 | 5 |
| | 25 | 20 | 20 | 250 | 0.32 | 1.17 | 5 |
| | 25 | 40 | 10 | 200 | 0.28 | 1.27 | 5 |
| | 25 | 40 | 20 | 450 | 0.31 | 1.4 | 5 |
| | 35 | 20 | 10 | 100 | 0.28 | 1.14 | 5 |
| | 35 | 20 | 20 | 200 | 0.33 | 1.432 | 5 |
| | 35 | 40 | 10 | 150 | 0.33 | 1.69 | 5 |
| | 35 | 40 | 20 | 400 | 0.34 | 1.85 | 5 |

Table A-1 Summary of Finite Element Runs

TABLE A-2
SPECIAL PROJECT TEST RUNS FOR ANISOTROPY AND NUMBER OF DRAINS

| | Number of Drains | Slope | Trial Radius | Spacing | Trench Elevation | Free Head | k horiz. | k vert. | Total Flow | Man Free Surface Influence | Radius of Influence | Total Flow | Man Free Surface |
|-----|---------------------|-------|-----------------|---------|---------------------|--------------|-------------|------------|---------------|----------------------------------|------------------------|---------------|---------------------|
| S8 | 4 | 3.5 | 100 | 25 | 60 | 10 | 0.2 | 0.02 | 0.1202 | 0.7863 | 350 | 0.08 | 0.6 |
| | 4 | 3.5 | 300 | 25 | 60 | 10 | 0.2 | 0.02 | 0.0533 | 0.4095 | | | |
| | 4 | 3.5 | 500 | 25 | 60 | 20 | 0.2 | 0.02 | 0.0492 | 0.347 | | | |
| S9 | 4 | 3.5 | 200 | 25 | 60 | 10 | 0.6 | 0.2 | 0.3166 | 0.8284 | 350 | 0.23 | 0.63 |
| | 4 | 3.5 | 400 | 25 | 60 | 10 | 0.6 | 0.2 | 0.2185 | 0.5862 | | | |
| | 4 | 3.5 | 600 | 25 | 60 | 10 | 0.6 | 0.2 | 0.2026 | 0.4979 | | | |
| S10 | 4 | 3.5 | 100 | 15 | 20 | 10 | 1.23 | 0.123 | 0.4001 | 0.2369 | 275 | 0.18 | 0.13 |
| | 4 | 3.5 | 300 | 15 | 20 | 10 | 1.23 | 0.123 | 0.1693 | 0.1253 | | | |
| | 4 | 3.5 | 500 | 15 | 20 | 10 | 1.23 | 0.123 | 0.1625 | 0.1024 | | | |
| S11 | 4 | 3.5 | 100 | 15 | 20 | 10 | 0.2 | 0.02 | 0.0651 | 0.2369 | 275 | 0.03 | 0.13 |
| | 4 | 3.5 | 300 | 15 | 20 | 10 | 0.2 | 0.02 | 0.0276 | 0.1253 | | | |
| | 4 | 3.5 | 500 | 15 | 20 | 10 | 0.2 | 0.02 | 0.0265 | 0.1024 | | | |
| S12 | 4 | 3.5 | 100 | 15 | 20 | 10 | 0.104 | 0.034 | 0.0639 | 0.4493 | 275 | 0.03 | 0.25 |
| | 4 | 3.5 | 300 | 15 | 20 | 10 | 0.104 | 0.034 | 0.0256 | 0.2425 | | | |
| | 4 | 3.5 | 500 | 15 | 20 | 10 | 0.104 | 0.034 | 0.0238 | 0.1981 | | | |
| S13 | 4 | 3.5 | 100 | 15 | 20 | 10 | 0.6 | 0.2 | 0.3723 | 0.4531 | 250 | 0.17 | 0.27 |
| | 4 | 3.5 | 300 | 15 | 20 | 10 | 0.6 | 0.2 | 0.15 | 0.2447 | | | |
| | 4 | 3.5 | 500 | 15 | 20 | 10 | 0.6 | 0.2 | 0.1388 | 0.1999 | | | |
| S15 | 3 | 3.5 | 100 | 15 | 20 | 10 | 0.2 | 0.2 | 0.3425 | 0.7908 | 325 | 0.13 | 0.37 |
| | 3 | 3.5 | 300 | 15 | 20 | 10 | 0.2 | 0.2 | 0.1344 | 0.389 | | | |
| | 3 | 3.5 | 500 | 15 | 20 | 10 | 0.2 | 0.2 | 0.1056 | 0.2925 | | | |
| S16 | 3 | 0 | 300 | 25 | 20 | 20 | 0.2 | 0.2 | 0.2894 | 0.715 | 700 | 0.13 | 0.33 |
| | 3 | 0 | 500 | 25 | 20 | 20 | 0.2 | 0.2 | 0.1822 | 0.4537 | | | |
| | 3 | 0 | 700 | 25 | 20 | 20 | 0.2 | 0.2 | 0.1322 | 0.3321 | | | |
| S17 | 3 | 7 | 100 | 35 | 20 | 20 | 0.2 | 0.2 | 0.5629 | 2.0473 | 275 | 0.29 | 1.25 |
| | 3 | 7 | 300 | 35 | 20 | 20 | 0.2 | 0.2 | 0.2713 | 1.1976 | | | |
| | 3 | 7 | 500 | 35 | 20 | 20 | 0.2 | 0.2 | 0.2653 | 0.9815 | | | |

TABLE A-3

| SPECIAL PROJECT TEST RUN DATA SUMMARY | | | | | | | | | | ::Dimensional Analysis Predict:: | | | |
|---------------------------------------|-------|--------------|---------|------------------|-----------|--------|---------|---------|----------------------------|----------------------------------|-------|------------------|------------------|
| Test | Slope | Trial Radius | Spacing | Trench Elevation | Free Head | k | | q-total | Free Surface Max Influence | Radius of Total Flow | | Max Free Surface | Max Free Surface |
| | | | | | | horiz. | vertic. | | | Influence | Flow | | |
| S1 | 5 | 200 | 20 | 40 | 15 | 0.2 | 0.2 | 0.76405 | 1.173 | 450 | 0.23 | 0.8 | 0.96 |
| | 5 | 400 | 20 | 40 | 15 | 0.2 | 0.2 | 1.4287 | 2.1591 | | | | |
| | 5 | 600 | 20 | 40 | 15 | 0.2 | 0.2 | 0.80464 | 1.799 | | | | |
| S2 | 3.5 | 400 | 25 | 40 | 20 | 0.2 | 0.2 | 1.59473 | 3.1004 | 610 | 0.205 | 0.86 | 0.96 |
| | 3.5 | 600 | 25 | 40 | 20 | 0.2 | 0.2 | 0.2005 | 0.8691 | | | | |
| | 3.5 | 800 | 25 | 40 | 20 | 0.2 | 0.2 | 0.3864 | 0.6093 | | | | |
| S3 | 0 | 200 | 35 | 30 | 10 | 0.2 | 0.2 | 0.8212 | 1.2552 | 400 | 0.09 | 0.24 | 0.39 |
| | 0 | 400 | 35 | 30 | 10 | 0.2 | 0.2 | 0.5464 | 1.1507 | | | | |
| | 0 | 600 | 35 | 30 | 10 | 0.2 | 0.2 | 1.0452 | 2.0982 | | | | |
| S5 | 3.5 | 200 | 15 | 50 | 10 | 0.2 | 0.2 | 0.2823 | 0.7822 | 400 | 0.16 | 0.54 | 0.7 |
| | 3.5 | 400 | 15 | 50 | 10 | 0.2 | 0.2 | 0.1564 | 0.5351 | | | | |
| | 3.5 | 600 | 15 | 50 | 10 | 0.2 | 0.2 | 0.128 | 0.4383 | | | | |
| S6 | 7 | 100 | 25 | 30 | 10 | 0.2 | 0.2 | 0.3186 | 1.247 | 150 | 0.3 | 1.05 | 1.07 |
| | 7 | 300 | 25 | 30 | 10 | 0.2 | 0.2 | 0.2714 | 0.8359 | | | | |
| | 7 | 500 | 25 | 30 | 10 | 0.2 | 0.2 | 0.2675 | 0.743 | | | | |
| S7 | 7 | 200 | 35 | 50 | 20 | 0.2 | 0.2 | 0.428 | 2.3121 | 350 | .35 | 1.8 | 1.41 |
| | 7 | 400 | 35 | 50 | 20 | 0.2 | 0.2 | 0.3947 | 1.7108 | | | | |
| | 7 | 600 | 35 | 50 | 20 | 0.2 | 0.2 | 0.3212 | 1.4832 | | | | |

APPENDIX B
SAMPLE INPUT AND OUTPUT

SAMPLE INPUT DATA FILE

"A35521"
2,0.00001
90,29,0,30,20,6,4,0
1,-190,6.65,1
7,-190,22.65,1
11,-190,36.65,0
18,-114,3.99,1
24,-114,19.99,1
28,-114,32.99,0
35,-43.7,1.5295,1
41,-43.7,17.5295,1
45,-43.7,29.5295,0
52,-19,0.665,1
58,-19,16.665,1
62,-19,27.665,0
69,0,0,1
75,0,16,1
79,0,25,0
86,10,-0.35,1
92,10,16,1
96,10,20,0
103,11.5,-0.4025,1
109,11.5,16,1
113,11.5,20,0
120,16.5,-0.5775,1
126,16.5,16,1
130,16.5,22,0
137,23,-0.805,1
143,23,16,1
147,23,22,0
154,25,-0.875,1
160,25,16,1
164,25,22,0
171,31.5,-1.1025,1
177,31.5,16,1
181,31.5,22,0
188,36.5,-1.2775,1
194,36.5,16,1
198,36.5,20,0
205,38,-1.33,1
211,38,16,1
215,38,20,0
222,43,-1.505,1
228,43,16,1
232,43,22,0
239,49.5,-1.7325,1
245,49.5,16,1
249,49.5,22,0
256,51.5,-1.8025,1
262,51.5,16,1
266,51.5,22,0
273,58,-2.03,1
279,58,16,1
283,58,22,0
290,63,-2.205,1

296,63,16,1
 300,63,20,0
 307,64.5,-2.2575,1
 313,64.5,16,1
 317,64.5,20,0
 324,69.5,-2.4325,1
 330,69.5,16,1
 334,69.5,22,0
 341,76,-2.66,1
 347,76,16,1
 351,76,22,0
 358,78,-2.73,1
 364,78,16,1
 368,78,22,0
 375,84.5,-2.9575,1
 381,84.5,16,1
 385,84.5,22,0
 392,89.5,-3.1325,1
 398,89.5,16,1
 402,89.5,20,0
 409,91,-3.185,1
 415,91,16,1
 419,91,20,0
 426,101,-3.535,1
 432,101,15.65,1
 436,101,21.465,0
 443,120,-4.2,1
 449,120,14.985,1
 453,120,21.8,0
 460,144.7,-5.0645,1
 466,144.7,14.1205,1
 470,144.7,22.9355,0
 477,215,-7.525,1
 483,215,11.66,1
 487,215,21.475,0
 494,291,-10.185,1
 500,291,9,1
 504,291,19.815,0
 1,12,18,19,20,13,3,2,4,0.2,0.2,0
 18,29,35,36,37,30,20,19,4,0.2,0.2,0
 35,46,52,53,54,47,37,36,4,0.2,0.2,0
 52,63,69,70,71,64,54,53,4,0.2,0.2,0
 69,80,86,87,88,81,71,70,4,0.2,0.2,0
 86,97,103,104,105,98,88,87,4,0.2,0.2,0
 103,114,120,121,122,115,105,104,4,0.2,0.2,0
 120,131,137,138,139,132,122,121,4,0.2,0.2,0
 137,148,154,155,156,149,139,138,4,0.2,0.2,0
 154,165,171,172,173,166,156,155,4,0.2,0.2,0
 171,182,188,189,190,183,173,172,4,0.2,0.2,0
 188,199,205,206,207,200,190,189,4,0.2,0.2,0
 205,216,222,223,224,217,207,206,4,0.2,0.2,0
 222,233,239,240,241,234,224,223,4,0.2,0.2,0
 239,250,256,257,258,251,241,240,4,0.2,0.2,0
 256,267,273,274,275,268,258,257,4,0.2,0.2,0
 273,284,290,291,292,285,275,274,4,0.2,0.2,0

290,301,307,308,309,302,292,291,4,0.2,0.2,0
 307,318,324,325,326,319,309,308,4,0.2,0.2,0
 324,335,341,342,343,336,326,325,4,0.2,0.2,0
 341,352,358,359,360,353,343,342,4,0.2,0.2,0
 358,369,375,376,377,370,360,359,4,0.2,0.2,0
 375,386,392,393,394,387,377,376,4,0.2,0.2,0
 392,403,409,410,411,404,394,393,4,0.2,0.2,0
 409,420,426,427,428,421,411,410,4,0.2,0.2,0
 426,437,443,444,445,438,428,427,4,0.2,0.2,0
 443,454,460,461,462,455,445,444,4,0.2,0.2,0
 460,471,477,478,479,472,462,461,4,0.2,0.2,0
 477,488,494,495,496,489,479,478,4,0.2,0.2,0
 1,36.65,5,2,1
 96,20,1,17,6
 198,20,1,17,6
 300,20,1,17,6
 402,20,1,17,6
 494,19.815,5,2,1
 11,7,28,24,45,41,62,58,79,75,96,92,113,109,130,126
 147,143,164,160,181,177,198,194,215,211,232,228,249,245,266,262
 283,279,300,296,317,313,334,330,351,347,368,364,385,381,402,398
 419,415,436,432,453,449,470,466,487,483,504,500
 17,34,51,68,85,102,119,136,153,170,187,204,221,238,255,272
 289,306,323,340,357,374,391,408,425,442,459,476,493
 96,1,17
 198,1,17
 300,1,17
 402,1,17
 "End of Problem"
 3,0.0001

SAMPLE OUTPUT

A35521

CE504CW

Userid: CE504CW
 File: CE504CW OUTPUT

F- .5902



1 .105
 2 .0349
 3 .0107
 4 .0026

| | | |
|----------|----------|----------|
| USERID | CE504CW | |
| ORIGIN | RSCS | |
| DISTCODE | CE504CW | |
| SYSTEM | GITVM1 | |
| SPOOLID | 8001 | |
| RECORDS | 00001063 | |
| FILE | CE504CW | OUTPUT |
| CREATED | 07/03/89 | 23:02:08 |
| PRINTED | 07/03/89 | 23:02:23 |
| CLASS | A | |
| FORMS | XD | |
| DEVICE | 600 | |
| SEQUENCE | 769 | |

NPPC = 56 NLEMC = 23 NPBC = 6 NPM = 30 TYCIV = 20 NPBC = 8 NPPAC = 4 TYIME = 6

GENERATED NODAL POINT DATA AND (X)-(Y) COORDINATES

| | | | | |
|----------|----|-----------|----|---------|
| NODE 1 | X= | -190.0000 | Y= | 5.8400 |
| NODE 2 | X= | -190.0000 | Y= | 11.8823 |
| NODE 5 | X= | -190.0000 | Y= | 17.3187 |
| NODE 7 | X= | -190.0000 | Y= | 22.8500 |
| NODE 8 | X= | -190.0000 | Y= | 28.8500 |
| NODE 11 | X= | -190.0000 | Y= | 38.8500 |
| NODE 18 | X= | -114.0000 | Y= | 3.8800 |
| NODE 20 | X= | -114.0000 | Y= | 8.3233 |
| NODE 22 | X= | -114.0000 | Y= | 12.8867 |
| NODE 24 | X= | -114.0000 | Y= | 18.0000 |
| NODE 26 | X= | -114.0000 | Y= | 28.4900 |
| NODE 28 | X= | -114.0000 | Y= | 32.8800 |
| NODE 36 | X= | -43.7000 | Y= | 1.8288 |
| NODE 37 | X= | -43.7000 | Y= | 6.8628 |
| NODE 38 | X= | -43.7000 | Y= | 12.1862 |
| NODE 41 | X= | -43.7000 | Y= | 17.5288 |
| NODE 43 | X= | -43.7000 | Y= | 23.8288 |
| NODE 46 | X= | -43.7000 | Y= | 28.8288 |
| NODE 52 | X= | -18.0000 | Y= | 8.8880 |
| NODE 54 | X= | -18.0000 | Y= | 8.8883 |
| NODE 58 | X= | -18.0000 | Y= | 11.3217 |
| NODE 60 | X= | -18.0000 | Y= | 18.8880 |
| NODE 62 | X= | -18.0000 | Y= | 22.1880 |
| NODE 68 | X= | 0.0000 | Y= | 0.0000 |
| NODE 71 | X= | 0.0000 | Y= | 8.3333 |
| NODE 73 | X= | 0.0000 | Y= | 10.8887 |
| NODE 75 | X= | 0.0000 | Y= | 18.0000 |
| NODE 77 | X= | 0.0000 | Y= | 20.8500 |
| NODE 79 | X= | 0.0000 | Y= | 28.0000 |
| NODE 88 | X= | 10.0000 | Y= | -1.3800 |
| NODE 88 | X= | 10.0000 | Y= | 8.1000 |
| NODE 90 | X= | 10.0000 | Y= | 10.8500 |
| NODE 92 | X= | 10.0000 | Y= | 18.0000 |
| NODE 94 | X= | 10.0000 | Y= | 18.0000 |
| NODE 96 | X= | 10.0000 | Y= | 20.0000 |
| NODE 103 | X= | 11.5000 | Y= | -1.4028 |
| NODE 105 | X= | 11.5000 | Y= | 8.0850 |
| NODE 107 | X= | 11.5000 | Y= | 10.5328 |
| NODE 109 | X= | 11.5000 | Y= | 18.0000 |
| NODE 111 | X= | 11.5000 | Y= | 18.0000 |
| NODE 113 | X= | 11.5000 | Y= | 20.0000 |
| NODE 120 | X= | 18.5000 | Y= | -1.8775 |
| NODE 122 | X= | 18.5000 | Y= | 4.8883 |
| NODE 124 | X= | 18.5000 | Y= | 10.4742 |
| NODE 126 | X= | 18.5000 | Y= | 18.0000 |
| NODE 128 | X= | 18.5000 | Y= | 18.0000 |
| NODE 130 | X= | 18.5000 | Y= | 22.0000 |
| NODE 132 | X= | 23.0000 | Y= | -1.8080 |
| NODE 138 | X= | 23.0000 | Y= | 4.7887 |
| NODE 141 | X= | 23.0000 | Y= | 10.3883 |
| NODE 143 | X= | 23.0000 | Y= | 18.0000 |
| NODE 145 | X= | 23.0000 | Y= | 18.0000 |
| NODE 147 | X= | 23.0000 | Y= | 22.0000 |
| NODE 164 | X= | 25.0000 | Y= | -1.8750 |
| NODE 158 | X= | 25.0000 | Y= | 4.7800 |

| | | | | |
|----------|----|---------|----|---------|
| NODE 168 | X= | 25.0000 | Y= | 10.3780 |
| NODE 180 | X= | 25.0000 | Y= | 18.0000 |
| NODE 182 | X= | 25.0000 | Y= | 18.0000 |
| NODE 184 | X= | 25.0000 | Y= | 22.0000 |
| NODE 171 | X= | 31.5000 | Y= | -1.1028 |
| NODE 173 | X= | 31.5000 | Y= | 4.8883 |
| NODE 175 | X= | 31.5000 | Y= | 10.2882 |
| NODE 177 | X= | 31.5000 | Y= | 18.0000 |
| NODE 178 | X= | 31.5000 | Y= | 18.0000 |
| NODE 181 | X= | 31.5000 | Y= | 22.0000 |
| NODE 188 | X= | 38.5000 | Y= | -1.2778 |
| NODE 190 | X= | 38.5000 | Y= | 4.4817 |
| NODE 192 | X= | 38.5000 | Y= | 10.2408 |
| NODE 194 | X= | 38.5000 | Y= | 18.0000 |
| NODE 195 | X= | 38.5000 | Y= | 18.0000 |
| NODE 198 | X= | 38.5000 | Y= | 20.0000 |
| NODE 205 | X= | 38.0000 | Y= | -1.3300 |
| NODE 207 | X= | 38.0000 | Y= | 4.4887 |
| NODE 208 | X= | 38.0000 | Y= | 10.2333 |
| NODE 211 | X= | 38.0000 | Y= | 18.0000 |
| NODE 213 | X= | 38.0000 | Y= | 18.0000 |
| NODE 215 | X= | 38.0000 | Y= | 20.0000 |
| NODE 222 | X= | 43.0000 | Y= | -1.8080 |
| NODE 224 | X= | 43.0000 | Y= | 4.3300 |
| NODE 226 | X= | 43.0000 | Y= | 10.1880 |
| NODE 228 | X= | 43.0000 | Y= | 18.0000 |
| NODE 230 | X= | 43.0000 | Y= | 18.0000 |
| NODE 232 | X= | 43.0000 | Y= | 22.0000 |
| NODE 239 | X= | 48.5000 | Y= | -1.7328 |
| NODE 241 | X= | 48.5000 | Y= | 4.1783 |
| NODE 243 | X= | 48.5000 | Y= | 10.0882 |
| NODE 245 | X= | 48.5000 | Y= | 18.0000 |
| NODE 247 | X= | 48.5000 | Y= | 18.0000 |
| NODE 248 | X= | 48.5000 | Y= | 22.0000 |
| NODE 255 | X= | 51.5000 | Y= | -1.8028 |
| NODE 256 | X= | 51.5000 | Y= | 4.1317 |
| NODE 260 | X= | 51.5000 | Y= | 10.0888 |
| NODE 262 | X= | 51.5000 | Y= | 18.0000 |
| NODE 264 | X= | 51.5000 | Y= | 18.0000 |
| NODE 268 | X= | 51.5000 | Y= | 22.0000 |
| NODE 273 | X= | 58.0000 | Y= | -2.0300 |
| NODE 276 | X= | 58.0000 | Y= | 3.8800 |
| NODE 277 | X= | 58.0000 | Y= | 8.8800 |
| NODE 279 | X= | 58.0000 | Y= | 18.0000 |
| NODE 281 | X= | 58.0000 | Y= | 18.0000 |
| NODE 283 | X= | 58.0000 | Y= | 22.0000 |
| NODE 290 | X= | 63.0000 | Y= | -2.2080 |
| NODE 292 | X= | 63.0000 | Y= | 2.8823 |
| NODE 294 | X= | 63.0000 | Y= | 8.9317 |
| NODE 298 | X= | 63.0000 | Y= | 18.0000 |
| NODE 298 | X= | 63.0000 | Y= | 18.0000 |
| NODE 300 | X= | 63.0000 | Y= | 20.0000 |
| NODE 307 | X= | 64.5000 | Y= | -2.2678 |
| NODE 309 | X= | 64.5000 | Y= | 3.8283 |
| NODE 313 | X= | 64.5000 | Y= | 18.0000 |
| NODE 315 | X= | 64.5000 | Y= | 18.0000 |
| NODE 317 | X= | 64.5000 | Y= | 20.0000 |
| NODE 324 | X= | 69.5000 | Y= | -2.4338 |
| NODE 326 | X= | 69.5000 | Y= | 3.7117 |
| NODE 328 | X= | 69.5000 | Y= | 8.8888 |
| NODE 330 | X= | 69.5000 | Y= | 18.0000 |
| NODE 332 | X= | 69.5000 | Y= | 18.0000 |
| NODE 334 | X= | 69.5000 | Y= | 22.0000 |
| NODE 341 | X= | 76.0000 | Y= | -2.8600 |

| | | | | |
|----------|---|----------|---|----------|
| NODE 361 | X | 78.0000 | Y | 22.0000 |
| NODE 362 | X | 78.0000 | Y | -2.7200 |
| NODE 363 | X | 78.0000 | Y | 3.5133 |
| NODE 364 | X | 78.0000 | Y | 8.7887 |
| NODE 365 | X | 78.0000 | Y | 16.0000 |
| NODE 366 | X | 78.0000 | Y | 18.0000 |
| NODE 367 | X | 78.0000 | Y | 22.0000 |
| NODE 368 | X | 84.5000 | Y | -2.8678 |
| NODE 369 | X | 84.5000 | Y | 3.3617 |
| NODE 370 | X | 84.5000 | Y | 8.8608 |
| NODE 371 | X | 84.5000 | Y | 18.0000 |
| NODE 372 | X | 84.5000 | Y | 18.0000 |
| NODE 373 | X | 88.5000 | Y | -3.1228 |
| NODE 374 | X | 88.5000 | Y | 3.2480 |
| NODE 375 | X | 88.5000 | Y | 8.8228 |
| NODE 376 | X | 88.5000 | Y | 18.0000 |
| NODE 377 | X | 88.5000 | Y | 18.0000 |
| NODE 400 | X | 88.5000 | Y | 20.0000 |
| NODE 402 | X | 88.5000 | Y | -3.1880 |
| NODE 403 | X | 81.0000 | Y | 3.2100 |
| NODE 411 | X | 81.0000 | Y | 8.8050 |
| NODE 412 | X | 81.0000 | Y | 18.0000 |
| NODE 413 | X | 81.0000 | Y | 18.0000 |
| NODE 414 | X | 81.0000 | Y | 20.0000 |
| NODE 428 | X | 101.0000 | Y | -3.5350 |
| NODE 429 | X | 101.0000 | Y | 2.8800 |
| NODE 430 | X | 101.0000 | Y | 8.2850 |
| NODE 432 | X | 101.0000 | Y | 15.8500 |
| NODE 434 | X | 101.0000 | Y | 18.5575 |
| NODE 436 | X | 101.0000 | Y | 21.4550 |
| NODE 443 | X | 120.0000 | Y | -4.2000 |
| NODE 445 | X | 120.0000 | Y | 2.1850 |
| NODE 447 | X | 120.0000 | Y | 8.5900 |
| NODE 449 | X | 120.0000 | Y | 14.8850 |
| NODE 451 | X | 120.0000 | Y | 18.3825 |
| NODE 453 | X | 120.0000 | Y | 21.8000 |
| NODE 480 | X | 144.7000 | Y | -5.0448 |
| NODE 482 | X | 144.7000 | Y | 1.3305 |
| NODE 484 | X | 144.7000 | Y | 7.7215 |
| NODE 486 | X | 144.7000 | Y | 14.1205 |
| NODE 488 | X | 144.7000 | Y | 18.5280 |
| NODE 470 | X | 144.7000 | Y | 22.9355 |
| NODE 477 | X | 218.0000 | Y | -7.5250 |
| NODE 478 | X | 218.0000 | Y | -1.1300 |
| NODE 481 | X | 218.0000 | Y | 5.2850 |
| NODE 483 | X | 218.0000 | Y | 11.5800 |
| NODE 485 | X | 218.0000 | Y | 18.5875 |
| NODE 487 | X | 218.0000 | Y | 21.4780 |
| NODE 489 | X | 281.0000 | Y | -10.1850 |
| NODE 496 | X | 281.0000 | Y | -3.7900 |
| NODE 498 | X | 281.0000 | Y | 2.8050 |
| NODE 500 | X | 281.0000 | Y | 8.0000 |
| NODE 502 | X | 281.0000 | Y | 14.4078 |
| NODE 504 | X | 281.0000 | Y | 18.8150 |

NUMBER OF NODAL POINTS 504

NUMBER OF ELEMENTS 145

ELE. NO. NODAL POINTS

| 1 | 1 | 12 | 18 | 19 | 20 | 13 | 3 | 2 | 20000E+00 | 20000E+00 | 0. |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----------|-----------|----|
| 2 | 3 | 13 | 20 | 21 | 22 | 14 | 5 | 4 | 20000E+00 | 20000E+00 | 0. |
| 3 | 6 | 14 | 22 | 23 | 24 | 15 | 7 | 5 | 20000E+00 | 20000E+00 | 0. |
| 4 | 7 | 15 | 24 | 25 | 26 | 16 | 8 | 6 | 20000E+00 | 20000E+00 | 0. |
| 5 | 8 | 16 | 26 | 27 | 28 | 17 | 11 | 10 | 20000E+00 | 20000E+00 | 0. |
| 6 | 18 | 28 | 35 | 36 | 37 | 30 | 20 | 19 | 20000E+00 | 20000E+00 | 0. |
| 7 | 20 | 30 | 37 | 38 | 39 | 31 | 22 | 21 | 20000E+00 | 20000E+00 | 0. |
| 8 | 22 | 31 | 38 | 40 | 41 | 32 | 24 | 23 | 20000E+00 | 20000E+00 | 0. |
| 9 | 24 | 32 | 41 | 42 | 43 | 33 | 26 | 25 | 20000E+00 | 20000E+00 | 0. |
| 10 | 26 | 33 | 43 | 44 | 45 | 34 | 28 | 27 | 20000E+00 | 20000E+00 | 0. |
| 11 | 35 | 48 | 52 | 53 | 54 | 47 | 37 | 36 | 20000E+00 | 20000E+00 | 0. |
| 12 | 37 | 47 | 54 | 55 | 56 | 48 | 38 | 37 | 20000E+00 | 20000E+00 | 0. |
| 13 | 38 | 48 | 55 | 57 | 58 | 49 | 41 | 40 | 20000E+00 | 20000E+00 | 0. |
| 14 | 41 | 49 | 58 | 59 | 60 | 50 | 43 | 42 | 20000E+00 | 20000E+00 | 0. |
| 15 | 43 | 50 | 60 | 61 | 62 | 51 | 45 | 44 | 20000E+00 | 20000E+00 | 0. |
| 16 | 52 | 63 | 68 | 70 | 71 | 64 | 54 | 53 | 20000E+00 | 20000E+00 | 0. |
| 17 | 54 | 64 | 71 | 72 | 73 | 65 | 56 | 55 | 20000E+00 | 20000E+00 | 0. |
| 18 | 58 | 68 | 73 | 74 | 75 | 68 | 58 | 57 | 20000E+00 | 20000E+00 | 0. |
| 19 | 59 | 69 | 75 | 76 | 77 | 69 | 60 | 59 | 20000E+00 | 20000E+00 | 0. |
| 20 | 60 | 67 | 77 | 78 | 79 | 66 | 62 | 61 | 20000E+00 | 20000E+00 | 0. |
| 21 | 69 | 80 | 86 | 87 | 88 | 81 | 71 | 70 | 20000E+00 | 20000E+00 | 0. |
| 22 | 71 | 81 | 88 | 89 | 90 | 82 | 73 | 72 | 20000E+00 | 20000E+00 | 0. |
| 23 | 73 | 82 | 90 | 91 | 92 | 83 | 75 | 74 | 20000E+00 | 20000E+00 | 0. |
| 24 | 75 | 83 | 92 | 93 | 94 | 84 | 77 | 76 | 20000E+00 | 20000E+00 | 0. |
| 25 | 77 | 84 | 94 | 95 | 96 | 85 | 78 | 78 | 20000E+00 | 20000E+00 | 0. |
| 26 | 86 | 97 | 103 | 104 | 105 | 88 | 88 | 87 | 20000E+00 | 20000E+00 | 0. |
| 27 | 88 | 98 | 105 | 106 | 107 | 89 | 90 | 89 | 20000E+00 | 20000E+00 | 0. |
| 28 | 90 | 99 | 107 | 108 | 109 | 90 | 92 | 91 | 20000E+00 | 20000E+00 | 0. |
| 29 | 92 | 100 | 108 | 110 | 111 | 101 | 94 | 93 | 20000E+00 | 20000E+00 | 0. |
| 30 | 94 | 101 | 111 | 112 | 113 | 102 | 96 | 95 | 20000E+00 | 20000E+00 | 0. |
| 31 | 103 | 114 | 120 | 121 | 122 | 115 | 105 | 104 | 20000E+00 | 20000E+00 | 0. |
| 32 | 105 | 115 | 122 | 123 | 124 | 116 | 107 | 106 | 20000E+00 | 20000E+00 | 0. |
| 33 | 107 | 116 | 124 | 125 | 126 | 117 | 109 | 108 | 20000E+00 | 20000E+00 | 0. |
| 34 | 108 | 117 | 125 | 127 | 128 | 118 | 111 | 110 | 20000E+00 | 20000E+00 | 0. |
| 35 | 111 | 118 | 128 | 129 | 130 | 119 | 113 | 112 | 20000E+00 | 20000E+00 | 0. |
| 36 | 120 | 131 | 137 | 138 | 139 | 122 | 121 | 120 | 20000E+00 | 20000E+00 | 0. |
| 37 | 122 | 132 | 139 | 140 | 141 | 123 | 124 | 123 | 20000E+00 | 20000E+00 | 0. |
| 38 | 124 | 133 | 141 | 142 | 143 | 124 | 126 | 125 | 20000E+00 | 20000E+00 | 0. |
| 39 | 126 | 134 | 143 | 144 | 145 | 125 | 128 | 127 | 20000E+00 | 20000E+00 | 0. |
| 40 | 128 | 135 | 145 | 146 | 147 | 126 | 130 | 128 | 20000E+00 | 20000E+00 | 0. |
| 41 | 127 | 148 | 154 | 155 | 156 | 148 | 139 | 138 | 20000E+00 | 20000E+00 | 0. |
| 42 | 138 | 149 | 155 | 157 | 158 | 150 | 141 | 140 | 20000E+00 | 20000E+00 | 0. |
| 43 | 141 | 150 | 158 | 159 | 160 | 151 | 143 | 142 | 20000E+00 | 20000E+00 | 0. |
| 44 | 143 | 151 | 160 | 161 | 162 | 152 | 145 | 144 | 20000E+00 | 20000E+00 | 0. |
| 45 | 145 | 152 | 162 | 163 | 164 | 153 | 147 | 146 | 20000E+00 | 20000E+00 | 0. |
| 46 | 154 | 165 | 171 | 172 | 173 | 158 | 156 | 155 | 20000E+00 | 20000E+00 | 0. |
| 47 | 156 | 166 | 173 | 174 | 175 | 157 | 158 | 157 | 20000E+00 | 20000E+00 | 0. |
| 48 | 164 | 167 | 176 | 177 | 178 | 168 | 160 | 159 | 20000E+00 | 20000E+00 | 0. |
| 49 | 166 | 168 | 177 | 178 | 179 | 169 | 162 | 161 | 20000E+00 | 20000E+00 | 0. |
| 50 | 162 | 189 | 179 | 180 | 181 | 170 | 164 | 163 | 20000E+00 | 20000E+00 | 0. |
| 51 | 171 | 182 | 188 | 189 | 190 | 183 | 173 | 172 | 20000E+00 | 20000E+00 | 0. |
| 52 | 173 | 183 | 190 | 191 | 192 | 184 | 175 | 174 | 20000E+00 | 20000E+00 | 0. |
| 53 | 175 | 184 | 192 | 193 | 194 | 185 | 177 | 176 | 20000E+00 | 20000E+00 | 0. |
| 54 | 177 | 185 | 194 | 195 | 196 | 186 | 179 | 178 | 20000E+00 | 20000E+00 | 0. |
| 55 | 179 | 186 | 196 | 197 | 198 | 187 | 181 | 180 | 20000E+00 | 20000E+00 | 0. |
| 56 | 188 | 199 | 206 | 207 | 208 | 190 | 189 | 188 | 20000E+00 | 20000E+00 | 0. |
| 57 | 190 | 200 | 207 | 208 | 209 | 201 | 192 | 191 | 20000E+00 | 20000E+00 | 0. |
| 58 | 192 | 201 | 208 | 210 | 211 | 202 | 194 | 193 | 20000E+00 | 20000E+00 | 0. |
| 59 | 194 | 202 | 211 | 212 | 213 | 203 | 196 | 195 | 20000E+00 | 20000E+00 | 0. |
| 60 | 196 | 203 | 213 | 214 | 215 | 204 | 198 | 197 | 20000E+00 | 20000E+00 | 0. |
| 61 | 206 | 216 | 222 | 223 | 224 | 217 | 207 | 206 | 20000E+00 | 20000E+00 | 0. |
| 62 | 207 | 217 | 224 | 225 | 226 | 218 | 209 | 208 | 20000E+00 | 20000E+00 | 0. |
| 63 | 208 | 218 | 225 | 227 | 228 | 219 | 211 | 210 | 20000E+00 | 20000E+00 | 0. |
| 64 | 211 | 219 | 228 | 229 | 230 | 220 | 213 | 212 | 20000E+00 | 20000E+00 | 0. |
| 65 | 213 | 220 | 230 | 231 | 232 | 221 | 215 | 214 | 20000E+00 | 20000E+00 | 0. |
| 66 | 222 | 233 | 238 | 240 | 241 | 234 | 224 | 223 | 20000E+00 | 20000E+00 | 0. |
| 67 | 224 | 234 | 241 | 242 | 243 | 235 | 226 | 225 | 20000E+00 | 20000E+00 | 0. |

| | | | | | | | | | | | |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----------|-----------|---|
| 71 | 238 | 250 | 256 | 267 | 258 | 261 | 241 | 240 | 20000E+00 | 20000E+00 | 0 |
| 72 | 241 | 251 | 258 | 269 | 260 | 262 | 243 | 242 | 20000E+00 | 20000E+00 | 0 |
| 73 | 243 | 252 | 260 | 271 | 262 | 263 | 245 | 244 | 20000E+00 | 20000E+00 | 0 |
| 74 | 245 | 253 | 262 | 273 | 264 | 264 | 247 | 246 | 20000E+00 | 20000E+00 | 0 |
| 75 | 247 | 254 | 264 | 268 | 266 | 266 | 248 | 248 | 20000E+00 | 20000E+00 | 0 |
| 76 | 256 | 267 | 273 | 274 | 276 | 268 | 268 | 267 | 20000E+00 | 20000E+00 | 0 |
| 77 | 258 | 268 | 275 | 276 | 277 | 269 | 260 | 259 | 20000E+00 | 20000E+00 | 0 |
| 78 | 260 | 269 | 277 | 278 | 279 | 270 | 262 | 261 | 20000E+00 | 20000E+00 | 0 |
| 79 | 262 | 270 | 278 | 280 | 281 | 271 | 264 | 263 | 20000E+00 | 20000E+00 | 0 |
| 80 | 264 | 271 | 281 | 282 | 283 | 272 | 266 | 265 | 20000E+00 | 20000E+00 | 0 |
| 81 | 273 | 284 | 290 | 291 | 292 | 288 | 275 | 274 | 20000E+00 | 20000E+00 | 0 |
| 82 | 275 | 285 | 292 | 293 | 294 | 288 | 277 | 276 | 20000E+00 | 20000E+00 | 0 |
| 83 | 277 | 286 | 294 | 295 | 296 | 287 | 279 | 278 | 20000E+00 | 20000E+00 | 0 |
| 84 | 278 | 287 | 296 | 297 | 298 | 288 | 281 | 280 | 20000E+00 | 20000E+00 | 0 |
| 85 | 281 | 288 | 298 | 299 | 300 | 289 | 283 | 282 | 20000E+00 | 20000E+00 | 0 |
| 86 | 280 | 301 | 307 | 308 | 309 | 302 | 292 | 291 | 20000E+00 | 20000E+00 | 0 |
| 87 | 282 | 302 | 308 | 310 | 311 | 303 | 294 | 293 | 20000E+00 | 20000E+00 | 0 |
| 88 | 284 | 303 | 311 | 312 | 313 | 304 | 296 | 295 | 20000E+00 | 20000E+00 | 0 |
| 89 | 288 | 304 | 313 | 314 | 315 | 308 | 298 | 297 | 20000E+00 | 20000E+00 | 0 |
| 90 | 288 | 308 | 318 | 318 | 317 | 308 | 300 | 298 | 20000E+00 | 20000E+00 | 0 |
| 91 | 307 | 318 | 324 | 326 | 326 | 318 | 308 | 308 | 20000E+00 | 20000E+00 | 0 |
| 92 | 308 | 318 | 326 | 327 | 328 | 320 | 311 | 310 | 20000E+00 | 20000E+00 | 0 |
| 93 | 311 | 320 | 328 | 329 | 330 | 321 | 313 | 312 | 20000E+00 | 20000E+00 | 0 |
| 94 | 313 | 321 | 330 | 331 | 332 | 322 | 315 | 314 | 20000E+00 | 20000E+00 | 0 |
| 95 | 316 | 322 | 332 | 333 | 334 | 323 | 317 | 316 | 20000E+00 | 20000E+00 | 0 |
| 96 | 324 | 336 | 341 | 342 | 343 | 336 | 328 | 326 | 20000E+00 | 20000E+00 | 0 |
| 97 | 326 | 336 | 343 | 344 | 345 | 337 | 328 | 327 | 20000E+00 | 20000E+00 | 0 |
| 98 | 328 | 337 | 345 | 346 | 347 | 338 | 330 | 328 | 20000E+00 | 20000E+00 | 0 |
| 99 | 330 | 338 | 347 | 348 | 349 | 339 | 332 | 331 | 20000E+00 | 20000E+00 | 0 |
| 100 | 332 | 339 | 348 | 350 | 351 | 340 | 334 | 333 | 20000E+00 | 20000E+00 | 0 |
| 101 | 341 | 352 | 358 | 359 | 360 | 353 | 343 | 342 | 20000E+00 | 20000E+00 | 0 |
| 102 | 343 | 353 | 360 | 361 | 362 | 354 | 345 | 344 | 20000E+00 | 20000E+00 | 0 |
| 103 | 345 | 354 | 362 | 363 | 364 | 356 | 347 | 346 | 20000E+00 | 20000E+00 | 0 |
| 104 | 347 | 355 | 364 | 365 | 366 | 358 | 349 | 348 | 20000E+00 | 20000E+00 | 0 |
| 105 | 349 | 356 | 366 | 367 | 368 | 357 | 351 | 350 | 20000E+00 | 20000E+00 | 0 |
| 106 | 358 | 369 | 375 | 376 | 377 | 370 | 360 | 358 | 20000E+00 | 20000E+00 | 0 |
| 107 | 360 | 370 | 377 | 378 | 379 | 371 | 362 | 361 | 20000E+00 | 20000E+00 | 0 |
| 108 | 362 | 371 | 378 | 380 | 381 | 372 | 364 | 363 | 20000E+00 | 20000E+00 | 0 |
| 109 | 363 | 372 | 381 | 382 | 383 | 373 | 365 | 364 | 20000E+00 | 20000E+00 | 0 |
| 110 | 368 | 373 | 383 | 384 | 385 | 374 | 368 | 367 | 20000E+00 | 20000E+00 | 0 |
| 111 | 375 | 386 | 392 | 393 | 394 | 387 | 377 | 376 | 20000E+00 | 20000E+00 | 0 |
| 112 | 377 | 387 | 394 | 395 | 396 | 388 | 379 | 378 | 20000E+00 | 20000E+00 | 0 |
| 113 | 379 | 388 | 396 | 397 | 398 | 389 | 381 | 380 | 20000E+00 | 20000E+00 | 0 |
| 114 | 381 | 389 | 398 | 399 | 400 | 390 | 383 | 382 | 20000E+00 | 20000E+00 | 0 |
| 115 | 383 | 390 | 400 | 401 | 402 | 391 | 385 | 384 | 20000E+00 | 20000E+00 | 0 |
| 116 | 382 | 403 | 409 | 410 | 411 | 404 | 394 | 393 | 20000E+00 | 20000E+00 | 0 |
| 117 | 384 | 404 | 411 | 412 | 413 | 406 | 398 | 395 | 20000E+00 | 20000E+00 | 0 |
| 118 | 388 | 406 | 413 | 414 | 415 | 408 | 398 | 397 | 20000E+00 | 20000E+00 | 0 |
| 119 | 388 | 406 | 415 | 416 | 417 | 407 | 400 | 398 | 20000E+00 | 20000E+00 | 0 |
| 120 | 400 | 407 | 417 | 418 | 419 | 408 | 402 | 401 | 20000E+00 | 20000E+00 | 0 |
| 121 | 409 | 420 | 426 | 427 | 428 | 421 | 411 | 410 | 20000E+00 | 20000E+00 | 0 |
| 122 | 411 | 421 | 428 | 429 | 430 | 422 | 413 | 412 | 20000E+00 | 20000E+00 | 0 |
| 123 | 413 | 422 | 430 | 431 | 432 | 423 | 415 | 414 | 20000E+00 | 20000E+00 | 0 |
| 124 | 415 | 423 | 432 | 433 | 434 | 424 | 417 | 416 | 20000E+00 | 20000E+00 | 0 |
| 125 | 417 | 424 | 434 | 435 | 436 | 425 | 419 | 418 | 20000E+00 | 20000E+00 | 0 |
| 126 | 428 | 437 | 443 | 444 | 445 | 438 | 428 | 427 | 20000E+00 | 20000E+00 | 0 |
| 127 | 428 | 436 | 445 | 446 | 447 | 439 | 430 | 429 | 20000E+00 | 20000E+00 | 0 |
| 128 | 430 | 438 | 447 | 448 | 449 | 440 | 432 | 431 | 20000E+00 | 20000E+00 | 0 |
| 129 | 432 | 440 | 449 | 450 | 451 | 441 | 434 | 433 | 20000E+00 | 20000E+00 | 0 |
| 130 | 434 | 441 | 451 | 452 | 453 | 442 | 436 | 435 | 20000E+00 | 20000E+00 | 0 |
| 131 | 443 | 454 | 460 | 461 | 462 | 455 | 445 | 444 | 20000E+00 | 20000E+00 | 0 |
| 132 | 445 | 455 | 462 | 463 | 464 | 456 | 447 | 446 | 20000E+00 | 20000E+00 | 0 |
| 133 | 447 | 456 | 464 | 465 | 466 | 457 | 448 | 448 | 20000E+00 | 20000E+00 | 0 |

| | | | | | | | | | | | |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----------|-----------|---|
| 134 | 449 | 457 | 466 | 467 | 468 | 458 | 451 | 450 | 20000E+00 | 20000E+00 | 0 |
| 135 | 451 | 458 | 468 | 469 | 470 | 459 | 453 | 452 | 20000E+00 | 20000E+00 | 0 |
| 136 | 460 | 471 | 477 | 478 | 479 | 472 | 462 | 461 | 20000E+00 | 20000E+00 | 0 |
| 137 | 462 | 472 | 479 | 480 | 481 | 473 | 464 | 463 | 20000E+00 | 20000E+00 | 0 |
| 138 | 464 | 473 | 481 | 482 | 483 | 474 | 466 | 465 | 20000E+00 | 20000E+00 | 0 |
| 139 | 465 | 474 | 483 | 484 | 485 | 475 | 468 | 467 | 20000E+00 | 20000E+00 | 0 |
| 140 | 468 | 478 | 488 | 489 | 490 | 478 | 470 | 468 | 20000E+00 | 20000E+00 | 0 |
| 141 | 477 | 486 | 494 | 495 | 496 | 488 | 479 | 478 | 20000E+00 | 20000E+00 | 0 |
| 142 | 479 | 488 | 496 | 497 | 498 | 490 | 481 | 480 | 20000E+00 | 20000E+00 | 0 |
| 143 | 481 | 490 | 498 | 499 | 500 | 491 | 483 | 482 | 20000E+00 | 20000E+00 | 0 |
| 144 | 483 | 491 | 500 | 501 | 502 | 493 | 484 | 483 | 20000E+00 | 20000E+00 | 0 |
| 145 | 485 | 492 | 502 | 503 | 504 | 493 | 487 | 486 | 20000E+00 | 20000E+00 | 0 |

| DIRICHLET BOUNDARY CONDITION DATA | | | | | | | | | | | |
|---|---------|---------|--|--|--|--|--|--|--|--|--|
| ONODES RESPECTIVE DIRICHLET BOUNDARY CONDITIONS | | | | | | | | | | | |
| 1- 2 | 38.8500 | 38.8500 | | | | | | | | | |
| 3- 4 | 38.8500 | 38.8500 | | | | | | | | | |
| 5- 6 | 38.8500 | 38.8500 | | | | | | | | | |
| 7- 8 | 38.8500 | 38.8500 | | | | | | | | | |
| 9- 10 | 38.8500 | 38.8500 | | | | | | | | | |
| 11- 10 | 38.8500 | 38.8500 | | | | | | | | | |
| 112-102 | 20.0000 | 20.0000 | | | | | | | | | |
| 113-102 | 20.0000 | 20.0000 | | | | | | | | | |
| 198-204 | 20.0000 | 20.0000 | | | | | | | | | |
| 218-204 | 20.0000 | 20.0000 | | | | | | | | | |
| 306-308 | 20.0000 | 20.0000 | | | | | | | | | |
| 317-308 | 20.0000 | 20.0000 | | | | | | | | | |
| 402-408 | 20.0000 | 20.0000 | | | | | | | | | |
| 418-408 | 20.0000 | 20.0000 | | | | | | | | | |
| 484-498 | 19.8150 | 19.8150 | | | | | | | | | |
| 498-497 | 19.8150 | 19.8150 | | | | | | | | | |
| 498-499 | 19.8150 | 19.8150 | | | | | | | | | |
| 500-501 | 19.8150 | 19.8150 | | | | | | | | | |
| 502-503 | 19.8150 | 19.8150 | | | | | | | | | |
| 504-503 | 19.8150 | 19.8150 | | | | | | | | | |

| NODAL POINTS ON FREE SURFACE | | | | | | | | | | | |
|------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 11 | 17 | 28 | 34 | 45 | 51 | 62 | 68 | 79 | 85 | 96 | 102 |
| 113 | 119 | 130 | 138 | 147 | 153 | 164 | 170 | | | | |
| 181 | 187 | 198 | 204 | 216 | 221 | 232 | 238 | 249 | 255 | 272 | 283 |
| 289 | 307 | 308 | 374 | 385 | 381 | 402 | 408 | 418 | 425 | 438 | 442 |
| 453 | 459 | 470 | 476 | 487 | 493 | 504 | | | | | |

| SEEPAGE FACE NODAL POINT DATA | | | | | | | | | | | |
|--|--|--|--|--|--|--|--|--|--|--|--|
| CONSECUTIVE NODE NUMBERS ON THE SEEPAGE FACE | | | | | | | | | | | |
| 98-113 | | | | | | | | | | | |
| 198-216 | | | | | | | | | | | |
| 306-377 | | | | | | | | | | | |
| 402-419 | | | | | | | | | | | |

| ITER = 1 | | | | | | | | | | | |
|--|-----|----------|-----|---------|--|--|--|--|--|--|--|
| NEW COORDINATES OF THE FREE SURFACE LINE | | | | | | | | | | | |
| NODE+487 | X : | 218.0000 | Y : | 19.8689 | | | | | | | |
| NODE+470 | X : | 144.7000 | Y : | 19.8582 | | | | | | | |
| NODE+463 | X : | 120.0000 | Y : | 19.8468 | | | | | | | |
| NODE+438 | X : | 101.0000 | Y : | 20.0034 | | | | | | | |
| NODE+419 | X : | 81.0000 | Y : | 20.0000 | | | | | | | |
| NODE+402 | X : | 69.0000 | Y : | 20.0000 | | | | | | | |
| NODE+386 | X : | 84.0000 | Y : | 20.0261 | | | | | | | |
| NODE+368 | X : | 78.0000 | Y : | 20.0367 | | | | | | | |

| | | | | |
|----------|-----|-----------|-----|---------|
| NODE+300 | X = | 83.0000 | Y = | 20.0000 |
| NODE+283 | X = | 58.0000 | Y = | 20.0872 |
| NODE+266 | X = | 51.5000 | Y = | 20.1386 |
| NODE+249 | X = | 48.5000 | Y = | 20.1421 |
| NODE+232 | X = | 43.0000 | Y = | 20.1490 |
| NODE+215 | X = | 38.0000 | Y = | 20.0000 |
| NODE+198 | X = | 38.5000 | Y = | 20.0000 |
| NODE+181 | X = | 31.5000 | Y = | 20.3274 |
| NODE+164 | X = | 28.0000 | Y = | 20.4657 |
| NODE+147 | X = | 23.0000 | Y = | 20.5182 |
| NODE+130 | X = | 18.5000 | Y = | 20.5218 |
| NODE+113 | X = | 11.5000 | Y = | 20.0000 |
| NODE+ 96 | X = | 10.0000 | Y = | 20.0000 |
| NODE+ 79 | X = | 0.0000 | Y = | 22.0334 |
| NODE+ 62 | X = | -18.0000 | Y = | 23.8688 |
| NODE+ 45 | X = | -43.7000 | Y = | 28.6188 |
| NODE+ 28 | X = | -114.0000 | Y = | 31.0307 |
| NODE+ 11 | X = | -190.0000 | Y = | 38.8500 |

ITER = 2

NEW COORDINATES OF THE FREE SURFACE LINE

| | | | | |
|----------|-----|-----------|-----|---------|
| NODE+487 | X = | 215.0000 | Y = | 19.8888 |
| NODE+470 | X = | 144.7000 | Y = | 19.8634 |
| NODE+453 | X = | 120.0000 | Y = | 19.8910 |
| NODE+436 | X = | 101.0000 | Y = | 20.0100 |
| NODE+419 | X = | 81.0000 | Y = | 20.0000 |
| NODE+402 | X = | 88.5000 | Y = | 20.0000 |
| NODE+385 | X = | 84.5000 | Y = | 20.0323 |
| NODE+368 | X = | 78.0000 | Y = | 20.0502 |
| NODE+351 | X = | 76.0000 | Y = | 20.0538 |
| NODE+334 | X = | 69.5000 | Y = | 20.0582 |
| NODE+317 | X = | 64.5000 | Y = | 20.0000 |
| NODE+300 | X = | 83.0000 | Y = | 20.0000 |
| NODE+283 | X = | 58.0000 | Y = | 20.1109 |
| NODE+266 | X = | 51.5000 | Y = | 20.1688 |
| NODE+249 | X = | 49.5000 | Y = | 20.1780 |
| NODE+232 | X = | 43.0000 | Y = | 20.1827 |
| NODE+215 | X = | 38.0000 | Y = | 20.0000 |
| NODE+198 | X = | 38.5000 | Y = | 20.0000 |
| NODE+181 | X = | 31.5000 | Y = | 20.3813 |
| NODE+164 | X = | 28.0000 | Y = | 20.5404 |
| NODE+147 | X = | 23.0000 | Y = | 20.5787 |
| NODE+130 | X = | 18.5000 | Y = | 20.5885 |
| NODE+113 | X = | 11.5000 | Y = | 20.0000 |
| NODE+ 96 | X = | 10.0000 | Y = | 20.0000 |
| NODE+ 79 | X = | 0.0000 | Y = | 21.8330 |
| NODE+ 62 | X = | -18.0000 | Y = | 23.7181 |
| NODE+ 45 | X = | -43.7000 | Y = | 28.6305 |
| NODE+ 28 | X = | -114.0000 | Y = | 31.3538 |
| NODE+ 11 | X = | -190.0000 | Y = | 38.8500 |

ITER = 3

NEW COORDINATES OF THE FREE SURFACE LINE

| | | | | |
|----------|-----|-----------|-----|---------|
| NODE+487 | X = | 215.0000 | Y = | 19.8888 |
| NODE+470 | X = | 144.7000 | Y = | 19.8638 |
| NODE+453 | X = | 120.0000 | Y = | 19.8912 |
| NODE+436 | X = | 101.0000 | Y = | 20.0102 |
| NODE+419 | X = | 81.0000 | Y = | 20.0000 |
| NODE+402 | X = | 88.5000 | Y = | 20.0000 |
| NODE+385 | X = | 84.5000 | Y = | 20.0325 |
| NODE+368 | X = | 78.0000 | Y = | 20.0505 |
| NODE+351 | X = | 76.0000 | Y = | 20.0542 |
| NODE+334 | X = | 69.5000 | Y = | 20.0585 |
| NODE+317 | X = | 64.5000 | Y = | 20.0000 |
| NODE+300 | X = | 83.0000 | Y = | 20.0000 |
| NODE+283 | X = | 58.0000 | Y = | 20.1115 |
| NODE+266 | X = | 51.5000 | Y = | 20.1877 |
| NODE+249 | X = | 49.5000 | Y = | 20.1788 |
| NODE+232 | X = | 43.0000 | Y = | 20.1834 |
| NODE+215 | X = | 38.0000 | Y = | 20.0000 |
| NODE+198 | X = | 38.5000 | Y = | 20.0000 |
| NODE+181 | X = | 31.5000 | Y = | 20.3837 |
| NODE+164 | X = | 28.0000 | Y = | 20.5432 |
| NODE+147 | X = | 23.0000 | Y = | 20.5784 |
| NODE+130 | X = | 18.5000 | Y = | 20.5902 |
| NODE+113 | X = | 11.5000 | Y = | 20.0000 |
| NODE+ 96 | X = | 10.0000 | Y = | 20.0000 |
| NODE+ 79 | X = | 0.0000 | Y = | 21.8483 |
| NODE+ 62 | X = | -18.0000 | Y = | 23.7517 |
| NODE+ 45 | X = | -43.7000 | Y = | 28.6817 |
| NODE+ 28 | X = | -114.0000 | Y = | 31.3582 |
| NODE+ 11 | X = | -190.0000 | Y = | 38.8500 |

ITER = 4

NEW COORDINATES OF THE FREE SURFACE LINE

| | | | | |
|----------|-----|-----------|-----|---------|
| NODE+487 | X = | 215.0000 | Y = | 19.8889 |
| NODE+470 | X = | 144.7000 | Y = | 19.8638 |
| NODE+453 | X = | 120.0000 | Y = | 19.8912 |
| NODE+436 | X = | 101.0000 | Y = | 20.0102 |
| NODE+419 | X = | 81.0000 | Y = | 20.0000 |
| NODE+402 | X = | 88.5000 | Y = | 20.0000 |
| NODE+385 | X = | 84.5000 | Y = | 20.0325 |
| NODE+368 | X = | 78.0000 | Y = | 20.0505 |
| NODE+351 | X = | 76.0000 | Y = | 20.0542 |
| NODE+334 | X = | 69.5000 | Y = | 20.0585 |
| NODE+317 | X = | 64.5000 | Y = | 20.0000 |
| NODE+300 | X = | 83.0000 | Y = | 20.0000 |
| NODE+283 | X = | 58.0000 | Y = | 20.1115 |
| NODE+266 | X = | 51.5000 | Y = | 20.1877 |
| NODE+249 | X = | 49.5000 | Y = | 20.1788 |
| NODE+232 | X = | 43.0000 | Y = | 20.1834 |
| NODE+215 | X = | 38.0000 | Y = | 20.0000 |
| NODE+198 | X = | 38.5000 | Y = | 20.0000 |
| NODE+181 | X = | 31.5000 | Y = | 20.3837 |
| NODE+164 | X = | 28.0000 | Y = | 20.5432 |
| NODE+147 | X = | 23.0000 | Y = | 20.5783 |
| NODE+130 | X = | 18.5000 | Y = | 20.5902 |
| NODE+113 | X = | 11.5000 | Y = | 20.0000 |
| NODE+ 96 | X = | 10.0000 | Y = | 20.0000 |
| NODE+ 79 | X = | 0.0000 | Y = | 21.8483 |
| NODE+ 62 | X = | -18.0000 | Y = | 23.7513 |
| NODE+ 45 | X = | -43.7000 | Y = | 28.6803 |
| NODE+ 28 | X = | -114.0000 | Y = | 31.3632 |
| NODE+ 11 | X = | -190.0000 | Y = | 38.8500 |

← F = .5902

CONVERGENCE CHECK ERROR = .3734E-06

| ONODE | X COORDINATE | Y COORDINATE | V-POTENTIAL | X-VELOCITY | Y-VELOCITY | TOTAL VELO. | PRES. COEF. |
|-------|--------------|--------------|-------------|------------|------------|-------------|-------------|
|-------|--------------|--------------|-------------|------------|------------|-------------|-------------|

| | | | | | | |
|----|-----------|---------|---------|-----------|----------|----------|
| 5 | -180.0000 | 17.3187 | 38.8500 | -1358E-01 | 1088E-03 | 1355E-01 |
| 6 | -180.0000 | 18.8833 | 38.8500 | -1348E-01 | 7180E-14 | 1348E-01 |
| 7 | -180.0000 | 22.8500 | 38.8500 | -1340E-01 | 1141E-03 | 1340E-01 |
| 8 | -180.0000 | 28.1500 | 38.8500 | -1330E-01 | 0. | 1330E-01 |
| 9 | -180.0000 | 28.8500 | 38.8500 | -1318E-01 | 1368E-03 | 1318E-01 |
| 10 | -180.0000 | 33.1500 | 38.8500 | -1307E-01 | 1094E-13 | 1307E-01 |
| 11 | -180.0000 | 38.8500 | 38.8500 | -1293E-01 | 1888E-03 | 1294E-01 |
| 12 | -182.0000 | 6.3200 | 33.8840 | -1419E-01 | 4429E-03 | 1420E-01 |
| 13 | -182.0000 | 10.8533 | 34.0034 | -1415E-01 | 5015E-03 | 1416E-01 |
| 14 | -182.0000 | 18.8867 | 34.0205 | -1411E-01 | 5899E-03 | 1412E-01 |
| 15 | -182.0000 | 21.3200 | 34.0389 | -1408E-01 | 6488E-03 | 1408E-01 |
| 16 | -182.0000 | 27.8500 | 34.0573 | -1387E-01 | 7488E-03 | 1387E-01 |
| 17 | -182.0000 | 34.0018 | 34.0757 | -1385E-01 | 8608E-03 | 1381E-01 |
| 18 | -114.0000 | 3.8900 | 31.2515 | -1487E-01 | 5174E-03 | 1486E-01 |
| 19 | -114.0000 | 8.8587 | 31.2540 | -1486E-01 | 5174E-03 | 1486E-01 |
| 20 | -114.0000 | 9.3233 | 31.2683 | -1486E-01 | 4387E-03 | 1486E-01 |
| 21 | -114.0000 | 11.8800 | 31.2735 | -1486E-01 | 8440E-03 | 1470E-01 |
| 22 | -114.0000 | 14.8587 | 31.2825 | -1486E-01 | 7800E-03 | 1471E-01 |
| 23 | -114.0000 | 17.3233 | 31.2822 | -1486E-01 | 7871E-03 | 1471E-01 |
| 24 | -114.0000 | 18.8500 | 31.3027 | -1470E-01 | 8728E-03 | 1472E-01 |
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| 477 | 215 0000 | -7 5280 | 18 8884 | - 2030E-03 | - 7147E-05 | 2031E-03 |
| 478 | 215 0000 | -4 3278 | 18 8888 | - 2028E-03 | - 8887E-05 | 2028E-03 |
| 479 | 215 0000 | -1 1300 | 18 8888 | - 2028E-03 | - 8800E-05 | 2028E-03 |
| 480 | 215 0000 | 2 0878 | 18 8887 | - 2028E-03 | - 4337E-05 | 2028E-03 |
| 481 | 215 0000 | 8 2880 | 18 8887 | - 2027E-03 | - 4018E-05 | 2027E-03 |
| 482 | 215 0000 | 8 4838 | 18 8888 | - 2027E-03 | - 2874E-05 | 2028E-03 |
| 483 | 215 0000 | 11 8800 | 18 8888 | - 2028E-03 | - 3274E-05 | 2028E-03 |
| 484 | 215 0000 | 13 7172 | 18 8888 | - 2028E-03 | - 1818E-05 | 2028E-03 |
| 485 | 215 0000 | 16 7744 | 18 8888 | - 2028E-03 | - 1283E-05 | 2028E-03 |
| 486 | 215 0000 | 17 8317 | 18 8888 | - 2028E-03 | - 8311E-05 | 2028E-03 |
| 487 | 215 0000 | 19 8888 | 18 8888 | - 2028E-03 | - 2231E-05 | 2028E-03 |
| 488 | 253 0000 | -8 8880 | 18 8807 | - 1930E-03 | - 8134E-05 | 1931E-03 |
| 489 | 253 0000 | -2 4800 | 18 8809 | - 1935E-03 | - 4848E-05 | 1936E-03 |
| 490 | 253 0000 | 3 8380 | 18 8810 | - 1940E-03 | - 3204E-05 | 1940E-03 |
| 491 | 253 0000 | 10 3300 | 18 8811 | - 1942E-03 | - 1928E-05 | 1943E-03 |
| 492 | 253 0000 | 18 0810 | 18 8812 | - 1944E-03 | - 1048E-05 | 1944E-03 |
| 493 | 253 0000 | 18 8818 | 18 8812 | - 1944E-03 | - 1176E-05 | 1944E-03 |
| 494 | 281 0000 | -10 1880 | 18 8180 | - 1828E-03 | - 1828E-05 | 1828E-03 |
| 495 | 281 0000 | -8 8878 | 18 8180 | - 1833E-03 | - 8882E-14 | 1833E-03 |
| 496 | 281 0000 | -3 7800 | 18 8180 | - 1841E-03 | - 1026E-05 | 1841E-03 |
| 497 | 281 0000 | - 8828 | 18 8180 | - 1848E-03 | - 5888E-14 | 1848E-03 |
| 498 | 281 0000 | 2 8080 | 18 8180 | - 1853E-03 | - 7019E-05 | 1853E-03 |
| 499 | 281 0000 | 8 8028 | 18 8180 | - 1858E-03 | - 8882E-14 | 1858E-03 |
| 500 | 281 0000 | 8 0000 | 18 8180 | - 1861E-03 | - 4027E-05 | 1861E-03 |
| 501 | 281 0000 | 11 7038 | 18 8180 | - 1864E-03 | 0 | 1864E-03 |
| 502 | 281 0000 | 14 4078 | 18 8180 | - 1868E-03 | - 2088E-05 | 1868E-03 |
| 503 | 281 0000 | 17 1113 | 18 8180 | - 1868E-03 | 0 | 1868E-03 |
| 504 | 281 0000 | 18 8180 | 18 8180 | - 1867E-03 | - 1488E-05 | 1867E-03 |

SUMMARY PAGE COMPUTATION RESULTS

| | | | | | | | | | | |
|-----------------------------|-----|----|-----|-----------|-----------|----|-----------|----|-----------|--------------------------|
| NR | 58 | NR | 113 | Ave. Vel. | 8880E-01 | DS | 15000E+01 | DO | 10488E+00 | #1 Trench g ₁ |
| TOTAL DISCHARGE = 10488E+00 | | | | | | | | | | |
| NR | 113 | NR | 188 | Ave. Vel. | 4880E-01 | DS | 28000E+02 | DO | 11488E+01 | #2 Trench g ₂ |
| TOTAL DISCHARGE = 12837E+01 | | | | | | | | | | |
| NR | 188 | NR | 215 | Ave. Vel. | 23288E-01 | DS | 18000E+01 | DO | 34842E+01 | |
| TOTAL DISCHARGE = 12887E+01 | | | | | | | | | | |
| NR | 215 | NR | 300 | Ave. Vel. | 14280E-01 | DS | 28000E+02 | DO | 38850E+00 | |
| TOTAL DISCHARGE = 18482E+01 | | | | | | | | | | |
| NR | 300 | NR | 317 | Ave. Vel. | 71801E-02 | DS | 18000E+01 | DO | 10728E+01 | #3 Trench g ₃ |
| TOTAL DISCHARGE = 18888E+01 | | | | | | | | | | |
| NR | 317 | NR | 402 | Ave. Vel. | 82404E-02 | DS | 25000E+02 | DO | 10801E+00 | |
| TOTAL DISCHARGE = 17818E+01 | | | | | | | | | | |
| NR | 402 | NR | 418 | Ave. Vel. | 17382E-02 | DS | 18000E+01 | DO | 28842E-02 | #4 Trench g ₄ |
| TOTAL DISCHARGE = 17848E+01 | | | | | | | | | | |
| "End of Program" | | | | | | | | | | |

APPENDIX C
DISCRIPTION OF COMPUTER PROCEDURES

APPENDIX C

APPENDIX C

Using a Personal Computer in Running the Aral Seepage Program

I. Introduction:

The Aral Seepage Program is located on the Georgia Institute of Technology main frame computer in the Cyber B area. To run many runs of the program it is very convenient to prepare and edit the data files on a personal computer, using an editor or word processor. A brief description of the method for this particular program follows. A user should get instruction and information for use of the Cyber B from the Office of Computer Services, Rich Building, Georgia Institute of Technology.

II. Preparing the Data Files:

Using the Aral Seepage Program User's Manual (Pirtle, Appendix A) draw and label the mesh for the problem to be run. An example is Figure 3-5 of this study, but a working copy of the mesh should be large enough for easy referral and use. With the mesh and a complete list of problem characteristics a data file can be prepared, from the user's manual instructions.

In this study the number of nodes and basic shape of the mesh was to be unchanged for all of the runs. To

simplify preparing the data files a spreadsheet was prepared. Changing the dimensions or hydraulic conductivities (vertical or horizontal) required one entry and the spreadsheet adjusted the node positions from simple formulas. The complexity of the spreadsheet is entirely dependent on the problem considered and the skill of the user with a spreadsheet program. Any of the commercially available programs will work satisfactorily. If the study will involve several different mesh arrangements and/or only a few runs the data file can more easily be prepared on an editor by typing it in, if the editor is set to create an ASCII file.

An ASCII file is a file of the characters as entered. Word processing programs and spreadsheet programs have hidden command codes which control the programs so that the features are executed. Features are the calculation of values in a spreadsheet or the margins, justification and format of a word processor.

Most spreadsheet programs have a function or ancillary utility program for conversion of the spreadsheet to a values separated by commas ASCII format. With that utility the spreadsheet no longer will do calculations or have the simple column alignment.

In this study the programs available provided an ASCII file with all values separated by commas. The file did have commas to separate what had been empty cells

within the spreadsheet. Other programs may not have that result. To delete the commas a word processor was used. A program which allows editing an ASCII file is necessary for this operation. If a word processor is used in the normal mode of edit command codes will be imbedded to set margins and the file will not run properly on the Aral Seepage Program.

III. Sending the Data File:

With a proper data file prepared running the Aral Seepage Program from a personal computer requires one device and several clearances. An authorization to use the Cyber B must be obtained, with a file storage area, a password and an identification code. This is explained by manuals available at the Office of Computer Services. Access to the Aral Seepage Program, named OWRCC must now be obtained from the School of Civil Engineering at the Mason Building. The device needed is a MODEM for transfer of data and commands to the Cyber B. The speed and manufacture of the MODEM is subject to the needs of the user.

A communications program is necessary to use the MODEM and many such programs are available. Georgia Tech offers students and faculty a program named COGITATE for use in communicating. In this study a different program was used but, it had the KERMIT file transfer program and

this is necessary.

With the communications program call the GTNET system and when a connection is made enter the GTNET command:

>> Connect *OCS CYBER B

A connection to this directory will be made and right to access will be challenged:

Family CYBERB

Userid (input the assigned ID)

Password (input the selected password)

Access will be granted to the Cyber B area. To copy the data file to your file for execution of the Aral Seepage Program the program COGITATE has menu entries to execute. If another communication program is used the KERMIT protocol is necessary. The details of this description are better left to someone else. In this study the following procedure worked.

\ KERMIT2

Control was now with the user's computer by use of KERMIT commands. Executing the "Send" command of KERMIT and naming the data file to be downloaded successfully transferred the file. The file name was changed as the cyber will use the first eight alpha-numeric characters of the name and ignore any periods normally used to separate suffixes in the MS-DOS environment. At the completion of sending data files execute the KERMIT command to "Finish" and control will be re-established

with the Cyber.

IV. Running the Program:

To run the program and receive a printed output from the laser printers in the Rich Building do the following:

\ OLD,OWRCC

\ GET,DATA (note:DATA is data file as named upon receipt by Cyber. To see names answer \ with LF)

\ OWRCC,DATA,PRINT (note:PRINT is name selected for the output by user. If no print is specified the output of the run will go to the screen. With a MODEM this is a very long process and is not recommended.)

A short wait of less than a minute can normally be expected here. If an error message is received the data file should be checked for errors in concept and tried again. If a transfer error is suspected send the file a second time.

\ SAVE,PRINT (note:SAVE only if a copy of the output is desired for the holding on Cyber)

\ PRINT? (note:A hard copy of the program output will be received in the Rich Building if the output file name PRINT is input at the first query and all other entries are allowed to default by responding with the "ENTER" or "RETURN" key. The last query asks for the USERID and responding with the ID has it printed on the cover of the hard copy for easier identification.

There are several other printer locations and many options one can exercise in printing the results. For more information consult the advisors in the Rich Building.

To exit from the Cyber:

\ LOGOUT

>> LOGOUT

V. Caution:

This appendix is not a replacement for the user's manuals of the programs used, nor for the instructions and guidance of the Office of Computer Services. It is a quick and easy guide of a procedure that has been successful in running programs on the Aral Seepage Program.

As stressed above many different programs will do the functions of the above procedure. For information the following were used:

Spreadsheet: SuperCalc 3

Editor: WordStar 4.0

Communications: ProComm 2.1

It would be an advantage if the output file from the Aral Seepage Program could be captured and downloaded from the Cyber. This was attempted with KERMIT once but, was discontinued after twenty minutes of transfer with a 1200 Baud MODEM.

APPENDIX D
SPREADSHEET AND DATA FILE DISKS

APPENDIX E
ARBITRARY SELECTION OF RADIUS

APPENDIX E

APPENDIX E

Arbitrary Selection of Radius

In this study the radius of influence was determined as the distance at which no more than a 10% decrease in total flow over a 100 foot change in trial radii occurs. This arbitrary selection is certainly open to discussion. It is very common for less restrictive criteria to be used in the definition of radius of influence of drawdown.

Figures E-1 and E-2 are cross section drawings of the free water surface in the trench area if the radius of influence had been selected at lower values based on some different arbitrary standard. Obviously the free surface reaches the upper blanket and possibly the foundation. The formulas used in Chapter 4 were based on field data of seepage and the field interpretation of the radius of influence, under some standard determination.

If the selection of radius of influence for this study had been based on a different criteria the predictive forms and dimensionless products would have been changed. Using a standard of $0.1 \text{ ft}^3/\text{day}/\text{ft}$, maximum change in trial radii of influence, Criteria A, results in Figures E-3 and E-4. These figures are the dimensionless product for a different standard of radius of influence. The new standard is on average $0.07 \text{ ft}^3/\text{day}/\text{ft}$ less restrictive and predict the radii of

TABLE E-1

SUMMARY OF DATA, CRITERIA A RADIUS DETERMINATION

| Slope | Sp | Hr | h | Li' (ft) | q' ft ² /day | F' (ft) |
|-------|----|----|----|-------------|----------------------------|------------|
| 0 | 15 | 20 | 10 | 250 | 0.18 | 0.28 |
| 0 | 25 | 20 | 10 | 250 | 0.15 | 0.31 |
| 0 | 35 | 20 | 10 | 250 | 0.15 | 0.36 |
| 0 | 15 | 20 | 20 | 400 | 0.25 | 0.4 |
| 0 | 25 | 20 | 20 | 400 | 0.22 | 0.45 |
| 0 | 35 | 20 | 20 | 350 | 0.22 | 0.58 |
| 0 | 15 | 60 | 10 | 350 | 0.22 | 0.45 |
| 0 | 25 | 60 | 10 | 300 | 0.21 | 0.65 |
| 0 | 35 | 60 | 10 | 300 | 0.2 | 0.75 |
| 0 | 15 | 60 | 20 | 450 | 0.35 | 0.76 |
| 0 | 25 | 60 | 20 | 450 | 0.32 | 0.93 |
| 0 | 35 | 60 | 20 | 450 | 0.3 | 1.05 |
| 3.5 | 15 | 20 | 10 | 200 | 0.2 | 0.48 |
| 3.5 | 25 | 20 | 10 | 100 | 0.21 | 0.73 |
| 3.5 | 35 | 20 | 10 | | | |
| 3.5 | 15 | 20 | 20 | 400 | 0.25 | 0.6 |
| 3.5 | 25 | 20 | 20 | 250 | 0.25 | 0.95 |
| 3.5 | 35 | 20 | 20 | 300 | 0.25 | 0.98 |
| 3.5 | 15 | 60 | 10 | 300 | 0.21 | 0.65 |
| 3.5 | 25 | 60 | 10 | 200 | 0.24 | 1.1 |
| 3.5 | 35 | 60 | 10 | 150 | 0.25 | 1.4 |
| 3.5 | 15 | 60 | 20 | 450 | 0.32 | 0.92 |
| 3.5 | 25 | 60 | 20 | 425 | 0.3 | 1.27 |
| 3.5 | 35 | 60 | 20 | 400 | 0.3 | 1.55 |
| 7 | 15 | 20 | 10 | 100 | 0.3 | 0.81 |
| 7 | 25 | 20 | 10 | | | |
| 7 | 35 | 20 | 10 | | | |
| 7 | 15 | 20 | 20 | 225 | 0.38 | 0.98 |
| 7 | 25 | 20 | 20 | 175 | 0.39 | 1.25 |
| 7 | 35 | 20 | 20 | 125 | 0.39 | 1.85 |
| 7 | 15 | 60 | 10 | 150 | 0.3 | 1.05 |
| 7 | 25 | 60 | 10 | 75 | 0.38 | 1.8 |
| 7 | 35 | 60 | 10 | 50 | 0.4 | 2.1 |
| 7 | 15 | 60 | 20 | 350 | 0.38 | 1.21 |
| 7 | 25 | 60 | 20 | 300 | 0.39 | 1.8 |
| 7 | 35 | 60 | 20 | 225 | 0.41 | 2.42 |

Table E-1. The new curves of dimensionless products in Figures E-3 and E-4 show the less restrictive curves to be nearly unchanged.

As a further check a second standard, Criteria B was developed. This standard is defined as a total flow increase of 75% from the total flow at a trial radius of 700 feet. The scatter plot of the dimensionless product versus total flow and maximum free surface is shown by Figures E-5 and E-6 for Criteria A and Criteria B. Table E-7 summarizes the results of Criteria B.

Figures E-7 and E-8 show the final curves for total flow and the maximum free surface against the dimensionless product for all considered standards. The curves are little changed. The use of one composite curve would suffice in predicting total flow and maximum free surface for any standard of radii determination.

An incorrect radius of influence will under predict the flow and maximum free surface if too high. A conservative approach would be to reduce the radius of influence as predicted from Figures 4-1,2 and 3. The amount of adjustment would require additional field data from a trench drain system.

FREE SURFACE PROFILE

Slope = 0%, L = 200', Spacing = 25'

H = 60', h = 20'

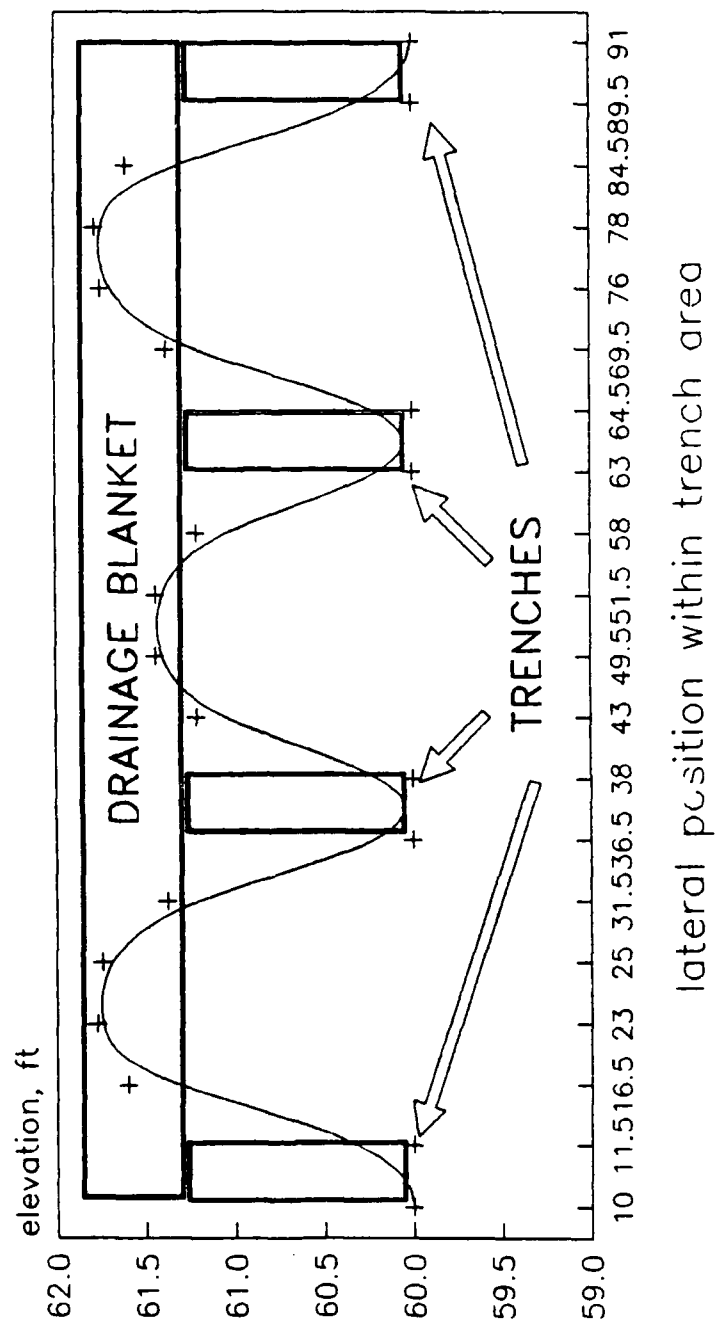


Fig. E-1
Free surface between trenches

FREE SURFACE PROFILE

Slope = 7%, L = 100', Spacing = 25'

H = 20', h = 20'

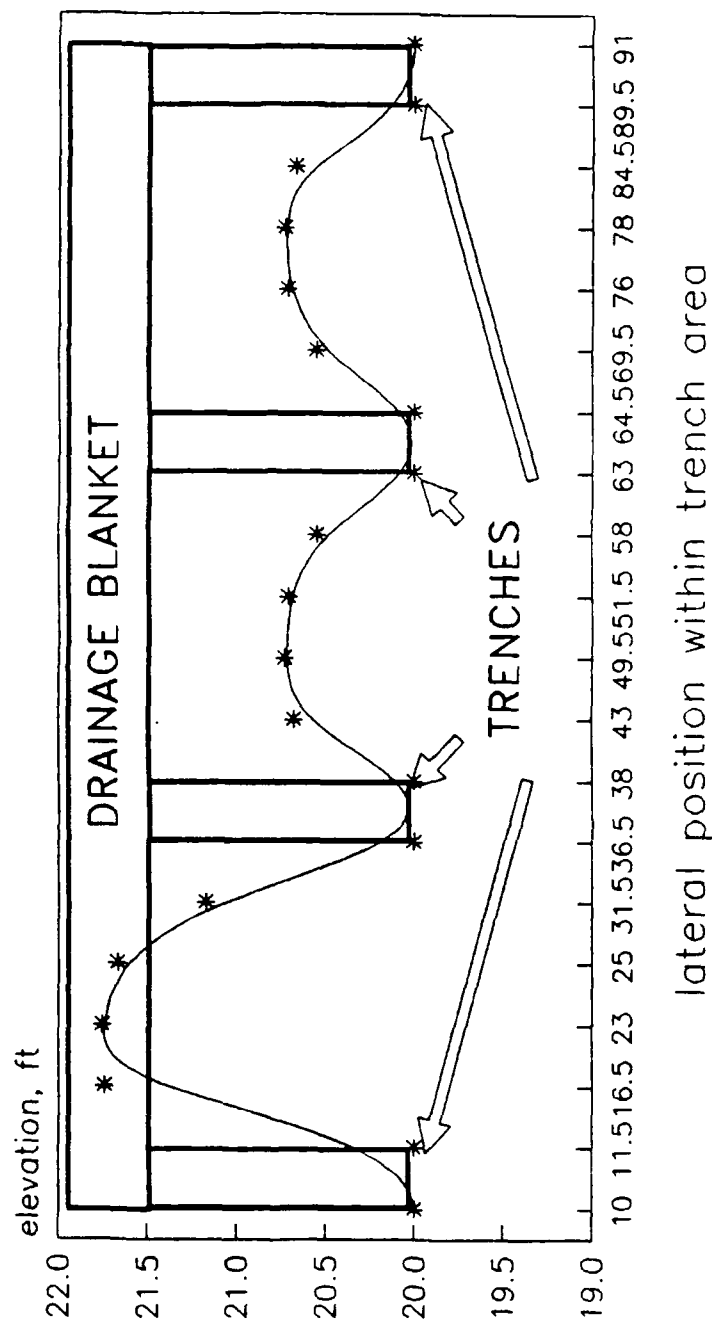


Fig. E-2
Free surface between trenches

TABLE E-2

SUMMARY OF DATA, CRITERIA B RADIUS DETERMINATION

| Slope | Sp | Hr | h | L ₁ ' (ft) | q' ft ² /day | F' (ft) |
|-------|----|----|----|--------------------------|----------------------------|------------|
| 0 | 15 | 20 | 10 | 325 | 0.12 | 0.26 |
| 0 | 25 | 20 | 10 | 400 | 0.1 | 0.21 |
| 0 | 35 | 20 | 10 | 500 | 0.09 | 0.16 |
| 0 | 15 | 20 | 20 | 400 | 0.26 | 0.4 |
| 0 | 25 | 20 | 20 | 375 | 0.23 | 0.46 |
| 0 | 35 | 20 | 20 | 375 | 0.21 | 0.65 |
| 0 | 15 | 60 | 10 | 400 | 0.19 | 0.44 |
| 0 | 25 | 60 | 10 | 425 | 0.18 | 0.6 |
| 0 | 35 | 60 | 10 | 400 | 0.18 | 0.7 |
| 0 | 15 | 60 | 20 | 400 | 0.4 | 0.8 |
| 0 | 25 | 60 | 20 | 375 | 0.39 | 1.05 |
| 0 | 35 | 60 | 20 | 400 | 0.35 | 1.15 |
| 3.5 | 15 | 20 | 10 | 200 | 0.19 | 0.48 |
| 3.5 | 25 | 20 | 10 | 100 | 0.19 | 0.73 |
| 3.5 | 35 | 20 | 10 | | | |
| 3.5 | 15 | 20 | 20 | 350 | 0.28 | 0.75 |
| 3.5 | 25 | 20 | 20 | 200 | 0.25 | 1.05 |
| 3.5 | 35 | 20 | 20 | 300 | 0.25 | 0.98 |
| 3.5 | 15 | 60 | 10 | 225 | 0.26 | 0.85 |
| 3.5 | 25 | 60 | 10 | 225 | 0.23 | 1.05 |
| 3.5 | 35 | 60 | 10 | 100 | 0.26 | 1.5 |
| 3.5 | 15 | 60 | 20 | 400 | 0.37 | 1.05 |
| 3.5 | 25 | 60 | 20 | 375 | 0.35 | 1.5 |
| 3.5 | 35 | 60 | 20 | 325 | 0.33 | 1.7 |
| 7 | 15 | 20 | 10 | | | |
| 7 | 25 | 20 | 10 | | | |
| 7 | 35 | 20 | 10 | | | |
| 7 | 15 | 20 | 20 | 175 | 0.45 | 1.3 |
| 7 | 25 | 20 | 20 | 150 | 0.47 | 1.5 |
| 7 | 35 | 20 | 20 | 100 | 0.52 | 2 |
| 7 | 15 | 60 | 10 | 125 | 0.35 | 1.3 |
| 7 | 25 | 60 | 10 | | | |
| 7 | 35 | 60 | 10 | | | |
| 7 | 15 | 60 | 20 | 300 | 0.45 | 1.4 |
| 7 | 25 | 60 | 20 | 225 | 0.49 | 1.95 |
| 7 | 35 | 60 | 20 | 150 | 0.56 | 3 |

TOTAL FLOW

(Four trench drains, 0 to 7% slope,
 $K_v = Kh$, trench width 1.5')

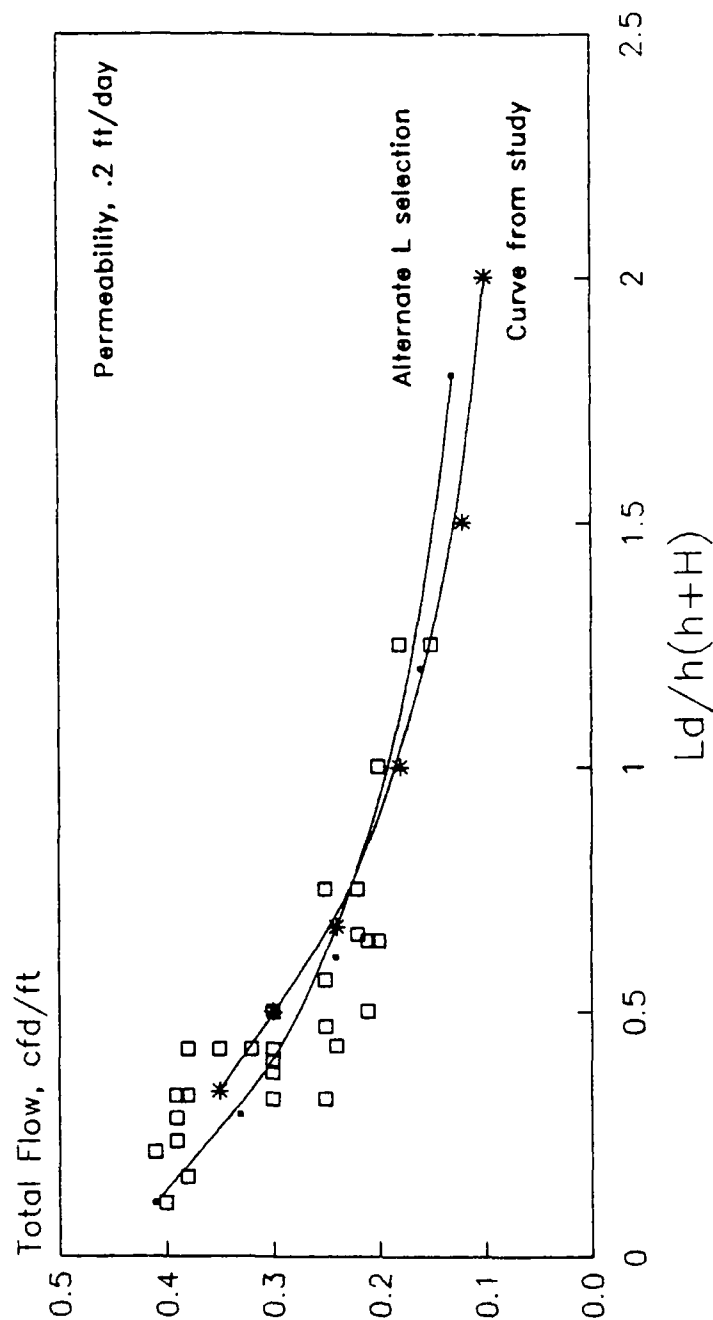


Fig. E-3
 Radius selected from alternate method

Max Free Surface

(Four trench drains, Slope 0 to 7%
 $K_v = K_h$, trench width 1.5')

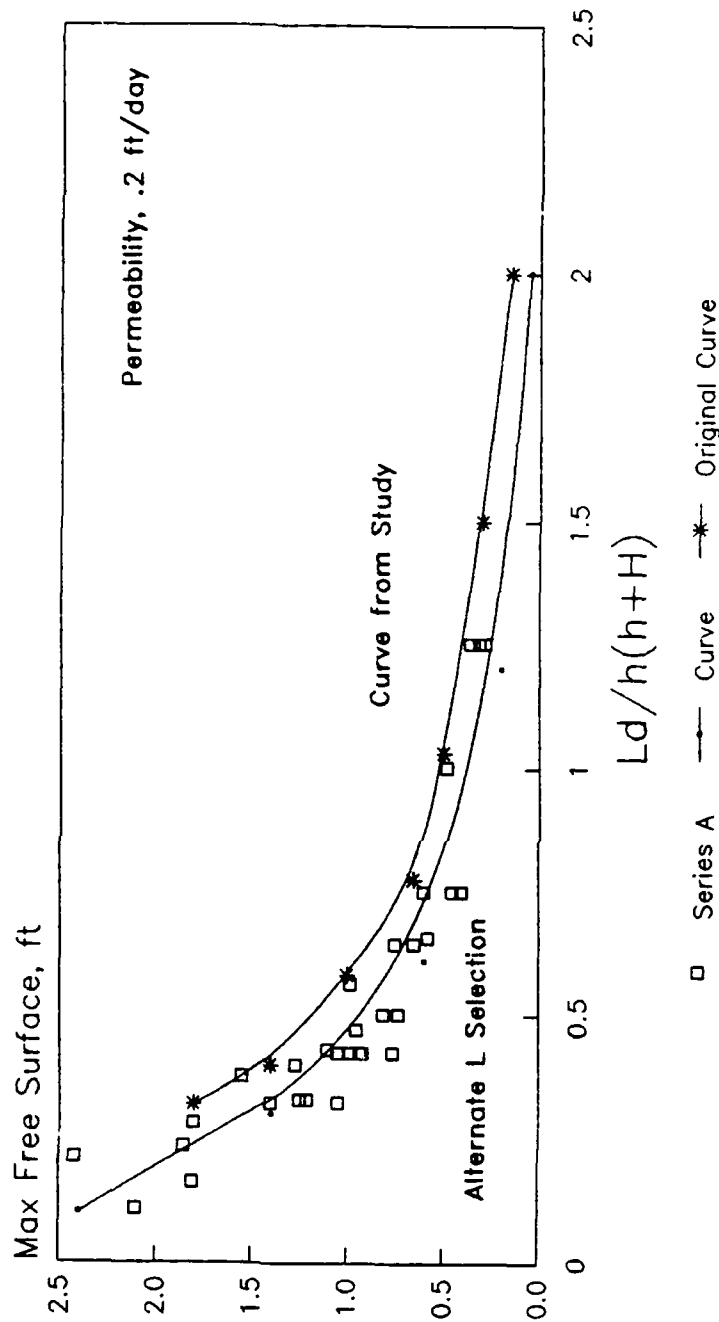


Fig. E-4
 Selection of L from alternate method

Total Flow

Radius from alternate methods

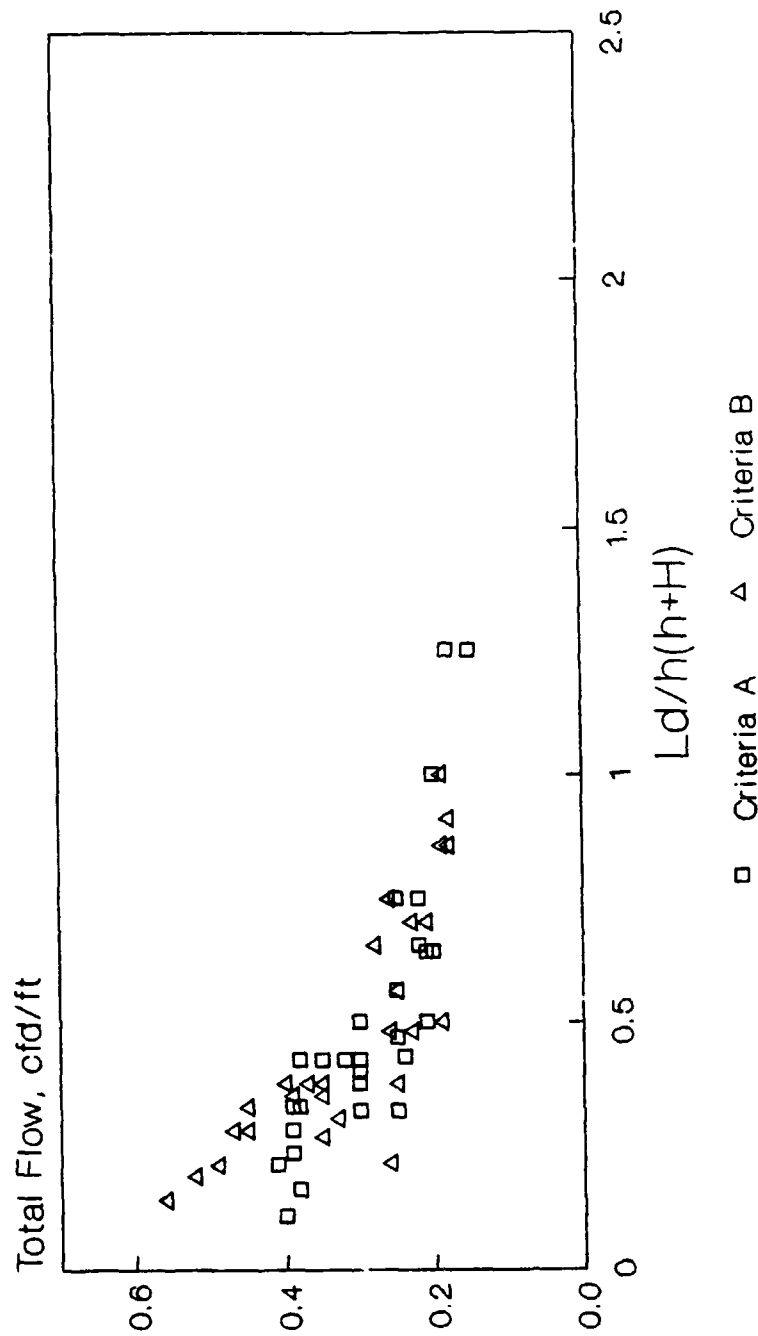


Fig E-5
Comparison of two alternate
criteria for radii determination

Max Free Surface

Radius from alternate method

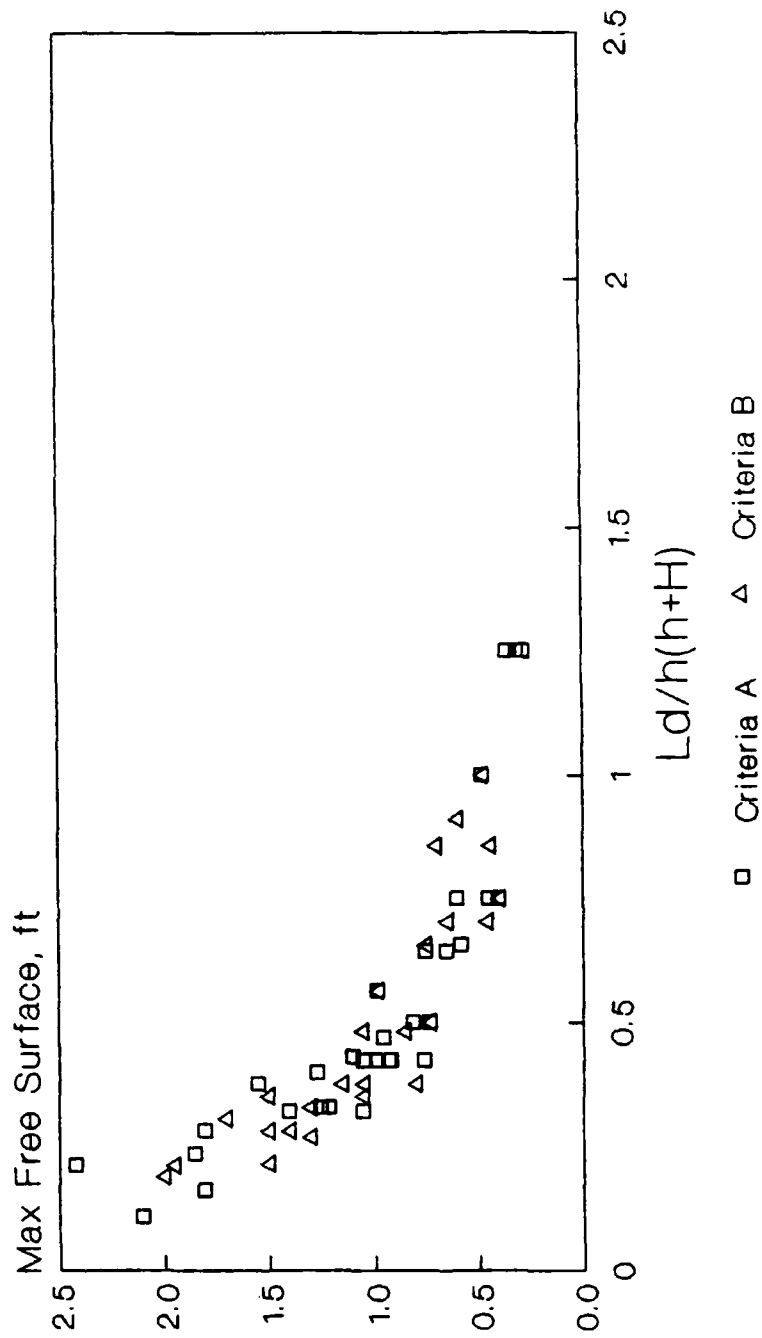


Fig. E-6
Comparison of two alternate
criteria for radii determination

Total Flow

Dimensionless Comparison from all radii determinations

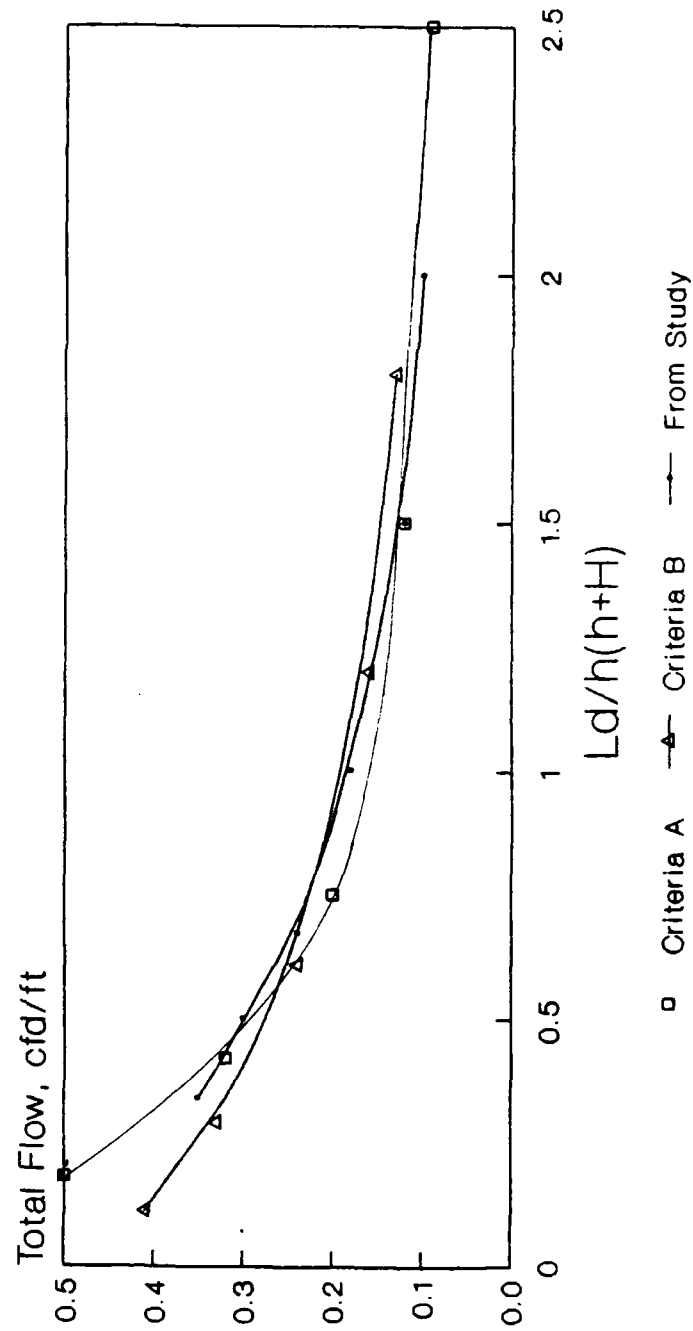


Fig. E-7
Primary and two alternate
radii determination methods

Maximum Free Surface

Dimensionless Comparison

from all radii determinations

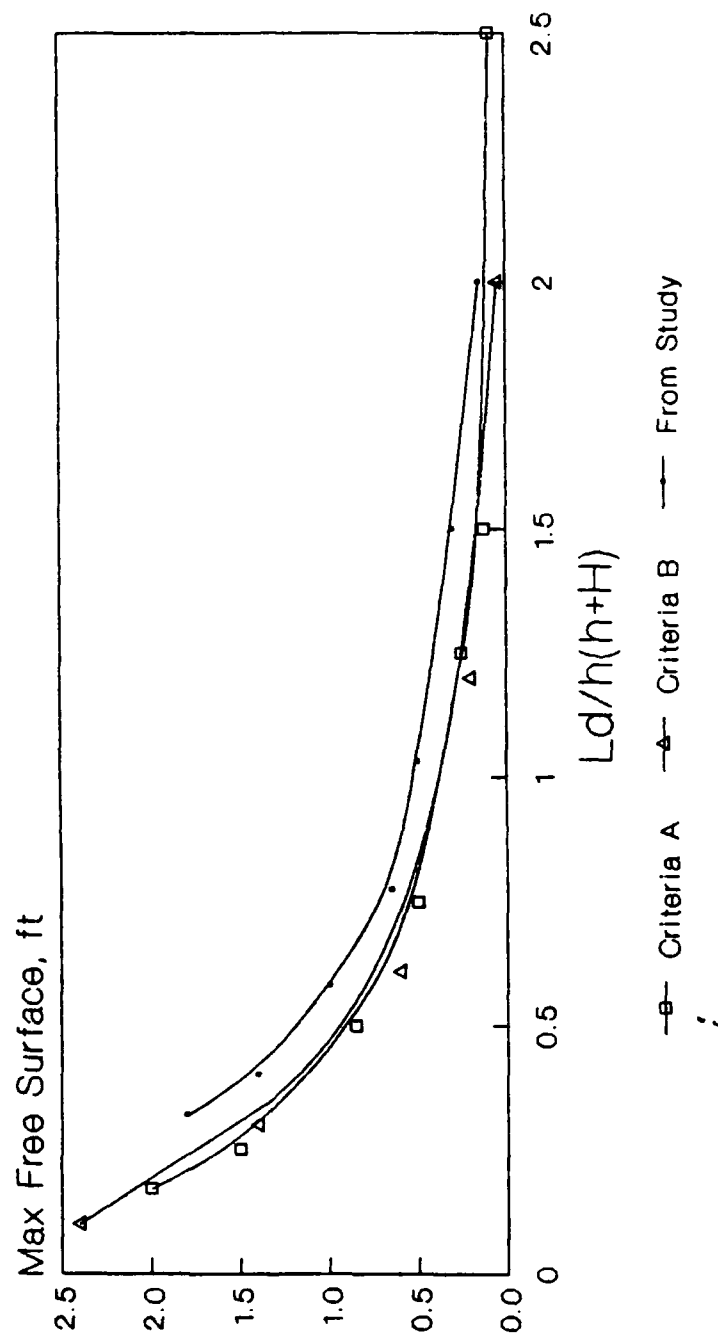


Fig. E-8
Primary and two alternate
radii determination methods